Series II, Volume 1 JANUARY 30, 1956 Number 1

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

PROGRAMME OF THE

1956 ANNUAL MEETING

TO BE HELD IN CONJUNCTION WITH
THE TWENTY-FIFTH ANNIVERSARY MEETING
OF THE AMERICAN INSTITUTE OF PHYSICS
AT
NEW YORK CITY

January 30 through February 3, 1956

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BULLETIN

of the

AMERICAN PHYSICAL SOCIETY

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AMERICAN PHYSICAL SOCIETY

1956 ANNUAL MEETING AT NEW YORK, JANUARY 30–FEBRUARY 3, 1956

THE American Institute of Physics will celebrate its **twenty-fifth anniversary** at the beginning of February 1956, and to assist in this grand and glorious event the **American Physical Society** will combine therewith its own **1956 Annual Meeting.** So also will the American Association of Physics Teachers, hereafter to be designated in these lines by AAPT. Our sessions, apart from the one next to be mentioned, will extend over Monday, January 30, Tuesday, Wednesday, and Friday. Our Joint Ceremonial Session with AAPT—comprising the addresses of our Retiring President, of the Richtmyer lecturer, and of the Oersted Medalist of AAPT—will be held on Thursday morning in the Manhattan Center; and the speakers invited by the Institute for its anniversary will be heard on Thursday afternoon, also in the Manhattan Center. There will be no competition with either of these stellar events. The Optical Society of America and the Acoustical Society of America will hold special sessions of invited papers on Wednesday, but we shall not be able to avoid competition with these. The Society of Rheology will join with our Division of High-Polymer Physics in a Symposium scheduled for Friday: it is described later in this Bulletin.

Although our papers are this year spread over four days and a half instead of the customary three, it does not follow that we have a correspondingly greater number of sessions. We have forty-four as against thirty-six last year, but not more than six at a time. This has the advantage of diminishing slightly the amount of competition between sessions and of enabling us to hold all sessions in two nearly contiguous buildings, the Manhattan Center and the Hotel New Yorker. On the other hand, we do not have so many large rooms as Columbia University used to offer us. These meetings in midtown New York are still in the experimental stage, and we do not know as yet whether we have found the most nearly perfect solution to our problems. We shall have more data at the end of this convention.

The administration of this meeting is in the hands of the American Institute of Physics and of S. A. Korff, Chairman of the Local Committee, to whom we owe our best thanks.

Hotels. The official hotel is the New Yorker, and the "overflow" hotel is the Statler. All reservations are to be made by use of the form on page 5 of this Bulletin, reprinted from the Chicago Bulletin.

The **registration desk** will be located on the mezzanine of the Hotel New Yorker. The **registration fee will be two dollars:** these Annual Meetings, what with the need of renting so capacious a hall as the Manhattan Center and of paying other expenses attendant on conventions in hotels, are costly affairs. Banquet tickets will be sold at the registration desk. Post-deadline papers, if any, will be announced on a blackboard near the registration desk. A message service will be set up but will not be functioning before Tuesday.

The **banquet of the American Institute of Physics,** in which our Society and all of the other Founder Societies will take part, will be held on Wednesday evening at 7:30 in the Grand Ballroom of the Hotel New Yorker. The after-dinner speakers will be I. I. Rabi and Jerome Schweitzer. The price of the dinner will be five dollars, and tickets will be sold at the registration desk up to five P.M. on Tuesday. Be sure to get yours by that time, else you will miss a very pleasurable experience.

The Institute will operate a **Placement Register** on Floors 5 and 6 and **instrument** and **book exhibits** on the mezzanine of the Hotel New Yorker. Copies of the January issue of *Physics Today*, containing a summary of the programmes of all meetings and a directory of exhibitors, will be available at the registration desk.

A programme for the **entertainment of ladies** has been arranged by Mrs. J. B. H. Kuper and Mrs. S. A. Korff. There will be a special desk at

the registration center to assist and advise the ladies. Information about the location of some of the better-known stores, the plays currently being presented, restaurants in the vicinity, and visits to Radio City Music Hall will be available at the desk. Maps will be provided. Inquiries should be made at the ladies' desk for the various tours which will be arranged.

Ladies desiring tickets to TV or radio shows will be assisted. They are reminded that some shows are very popular and often filled far ahead. Any ladies who wish to ask for ticket reservations may do so by writing to Mrs. J. B. H. Kuper, Brookhaven National Laboratories, Upton, Long Island, New York, stating **which shows they prefer.** Available tickets will be held at the ladies' desk for a reasonable time. The tickets generally are free.

Our **Division of Electron Physics** is holding a Symposium on Tuesday morning. Our **Division of High-Polymer Physics**, in conjunction with the Society of Rheology, has arranged a Symposium, "Rheology of Polymers," to be held on Friday, both morning and afternoon. Our **Division of Fluid Dynamics** has no symposium, but the attention of its members is drawn to its Business Meeting to be held during Session D.

A symposium in biophysics has been arranged by E. L. Quimby, and is scheduled for Wednesday morning.

On Tuesday evening, January 31, at 8:00 P.M., in Parlor A of the Hotel New Yorker, there will be a discussion of formal organization of biophysicists. Anyone interested in this meeting is invited to attend.

A **symposium about *K*-mesons** has been arranged by E. T. Booth and L. M. Lederman and is scheduled for Wednesday afternoon. A number of invited papers in various fields appear in the general programme, and the names of their authors will be found in the Epitome.

Three hundred and sixty-six contributed papers have been distributed among thirty-six sessions. The corresponding figures for the 1955 Annual Meeting were 329 and thirty. Theoretical physics is bursting at the seams. There is now quite a problem in arranging the sessions so that theoretical papers do not coincide with time with relevant experimental papers. It is not pretended that this problem has been well solved. S. Borowski has kindly arranged the abstracts in theoretical physics, a task beyond the Secretary's competence.

The **Business Meeting of the Society** will be held at 1:45 P.M. on Friday in the Grand Ballroom of the Hotel New Yorker. Other sessions of Friday afternoon will be scheduled to commence at 2:45 P.M.

The **Council of the American Physical Society** will meet on Monday afternoon (January 30) at two in the building of the American Institute of Physics, 57 East 55th Street, New York 22, New York, unless contrary notice is distributed to its members.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special importance, will be considered for admission to a special supplementary programme if the abstracts are received at the office of the Society not later than Monday, January 23. The titles of such as are accepted will be announced on a blackboard near the registration desk, and the papers will be given under the usual ten-minute rule at the end of the session (N). The abstracts will not be published. Those who submit post-deadline papers will not be able to find out whether their papers are admitted without coming to the meeting.

Preliminary announcements of the Houston and Pittsburgh meetings appear on page 3 of this Bulletin, and the calendar of meetings for the remainder of the season 1955–1956 on page 4 with instructions for the preparation of abstracts.

Important change in policy. From now on, the abstracts appearing in this Bulletin will *not* be republished in *The Physical Review*. Errata will be published in a subsequent issue of the Bulletin if received by Miss Ruth Bryans, 57 East 55th Street, New York 22, New York, not later than three weeks after the distribution of this Bulletin. Do not send in the text of the abstract marked with corrections: write out the corrections in the form "instead of . . . read. . . ." Add nothing!

An endeavor will be made to provide as many copies of the Bulletin at each meeting as will suffice for those who attend the meeting and pay the registration fee. This will enable our members to keep unblemished for future binding the issues that they receive through the mails. As for nonmember subscribers to *The Physical Review*, they are admonished hereby, as they have been already, that they must subscribe to the *Bulletin* if they wish to have the abstracts on their shelves.

To mark the changeover for posterity, we now start Series II of the Bulletin, and this is the first issue of Series II volume I. The time will come when the existence of a previous series will be as little remembered as presently is the existence of a first series of *The Physical Review*.

The undersigned has been appointed editor of this Bulletin.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

Second Announcement of the Houston Meeting

The 1956 meeting of the American Physical Society in the Southwest will be held on Friday and Saturday, February 24 and 25, in the Rice Institute, Houston, Texas. Rooms have been set aside for our members in the Rice Hotel and in the Shamrock-Hilton Hotel; reservation should be made early.

Preliminary Announcement of the Pittsburgh Meeting

The 1956 March meeting of the American Physical Society will be held in Pittsburgh, Pennsylvania, on Thursday, Friday, and Saturday, March 15, 16, and 17. The official hotels are the Webster Hall (singles without bath $4.25, singles with bath $7.50 to $9.00, doubles with bath $10, $12, and $15) and the Schenley Park (singles $7 to $13.50, doubles $10 to $17.50). Deadline is Friday January thirteenth, and abstracts are to be sent to the office of the American Physical Society, Columbia University, New York 27, New York.

Recordings of the Fermi Memorial Session

One of the most outstanding events in the history of the American Physical Society was the session honoring Enrico Fermi, held at the 1955 Washington meeting of the Society. This consisted of addresses by H. L. Anderson, E. Konopinski, F. Seitz, E. Segrè, and W. H. Zinn, and of the words by which H. A. Bethe as Chairman (and organizer of the session) introduced the session as a whole and the speakers severally. These addresses and Bethe's remarks were recorded on tape by R. E. Wolford and J. B. Wise, whose avocation is the making of records, and who made these gratuitously as a service to the Society. Through their courtesy also, reproductions of the records on tape or disk will be made available in any quantity and may be purchased at no more than cost. The six records, either in form of tape (7-inch reel, $\frac{1}{4}$-inch tape, 1200 or 1800 feet in length) or 12-inch microgroove LP disk, will be sold separately or all together. The price for the whole set, tape or disk, will be $30.00. The price for any disk is $5.00; the price for the tapes of Anderson, Bethe, Konopinski, and Seitz is $5.00 for each; the price for the (longer) tapes of Segrè and Zinn is $7.50 each. These figures include postage in the United States, Canada, and Mexico.

Checks or money orders (no cash please) should be made payable to the American Physical Society and mailed to Dr. R. D. Huntoon, National Bureau of Standards, Washington 25, D. C. Anyone who places an order from other countries should ascertain the postage required, deduct 50 cents, and remit the difference with his order. The shipping weight is one pound for each disk or tape.

(Please keep this page on file!)

MEETINGS AND DEADLINES FOR THE SEASON 1955–1956

Place	*Meeting dates*	*Deadline date*
Los Angeles	December 28–30	past
New York	January 30–February 3	past
Houston	February 24–25	December 30
Pittsburgh	March 15–17	January 13
Washington	April 26–28	February 17
New Haven	June 21–23	April 27
Eugene*	June 21–23	not decided

* Abstracts for the Eugene meeting are to be sent to W. A. NIERENBERG, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date.

Abstracts for the other meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. To avoid chance of confusion, please do not send an abstract for any meeting until the deadline date of the previous meeting is at least five days past.

RULES PRESCRIBED FOR ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten and double-spaced; one must be an original, the other may be an original or a carbon copy. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Do not use very thin paper; a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged, and follow the example. Issues of the *Bulletin* are sometimes appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line. **By action of our Council, abstracts will not henceforth be withdrawn from our proofs unless the asker sends ten dollars with his request.**

HOTEL INFORMATION

January 30–February 4, 1956

The New Yorker is the headquarters hotel. Reservations should be sent directly to Mr. John Grundhofer, Front Office Manager of the New Yorker, in the manner directed below. Overflow will be accommodated at the Statler. The New Yorker will forward late reservations to the Statler for confirmation to you. Please tear off the attached and use as your room reservation blank. Be sure to specify the persons for whom reservations are being made. All rates quoted are for the room, and in the event of more than one person occupying the room the rate can be shared. If a third person is housed in the room, the cost of the extra "roll-away" bed will be added to the cost of the room.

If a room at the rate requested is not available, one at the nearest available rate will be reserved for you. Be sure to bring the confirmation slip with you as proof of your reservation. In fairness to others, please make a cancellation if your plans change. Unless otherwise requested the hotels will hold reservations only to 6 P.M. of the day of your arrival. Check out time is 3 P.M.

HOTEL RATES

HOTELS	Room and Bath for one per day	Double-Bed Room with Bath for two per day	Twin-Bed Room with Bath for two per day	One Room for 3 persons with bath per day	Suites Living Room Bedroom and Bath for one or two per day
New Yorker 34th Street at 8th Avenue	$7.00–$ 9.00	$ 9.00–$12.00	$10.50–$16.00	$12.00–$15.00	$25.00 and up
Statler 7th Avenue at 33rd Street	$8.00–$10.00	$10.00–$14.00	$11.00–$18.00	$13.00–$18.00	$30.00 and up

NOTE: All rates subject to New York City 5% hotel room tax.

Tear Off

Tear Off

To: FRONT OFFICE MANAGER
HOTEL NEW YORKER
34TH STREET AND 8TH AVENUE
NEW YORK, NEW YORK

A.I.P.

Please enter my reservation for a single / double bedroom / twin at approx. $..... to $..... per day for the 1956 A.I.P. Convention. I / We plan to arrive ..... and remain until .....

Print below Persons in Your Party

.....
Signature

.....
Address (Street or P.O.)

.....
Town or City and State

EPITOME OF THE 1956 ANNUAL MEETING

(Personal names are those of invited speakers. Halls, unless otherwise indicated, are in the Hotel New Yorker)

Monday Morning

A. Fission; the antiproton; Chamberlain, Lee. Grand Ballroom.
AB. Nuclear and electronic scattering; diverse topics. Panel Room.
B. Magnetic resonance and allied topics. Terrace.
BA. Microwave and band spectra. Empire.
C. Fluid dynamics, I. Manhattan Center, Gold Room.
CA. Theoretical physics I. Boston Room.

Monday Afternoon

D. Fluid dynamics, II; Business session of division of fluid dynamics. Manhattan Center, Gold Room.
DA. Reactions of transmutation and nuclear energy levels, He through C. Grand Ballroom.
E. Optical physics; Jackson. Empire.
EA. Ferromagnetics. Terrace.
F. Theoretical physics, II. Boston Room.

Tuesday Morning

G. Division of Electron Physics: Fan, Weissler, Lassettre; business meeting. Electron physics. Manhattan Center, Gold Room.
GA. Reactions of transmutation and nuclear energy levels, Mg through Si. Grand Ballroom.
H. Sherr; radioactive nuclei, I. Terrace.
HA. Solid-state physics: nonmetals. Panel.
I. General physics; atmospheric physics; H. K. Kallmann. Empire.
IA. Theoretical physics, III. Boston Room.

Tuesday Afternoon

J. Dyke, Mueller; electron physics. Manhattan Center, Gold Room.
JA. Reactions of transmutation and nuclear energy levels, P through Au; general. Grand Ballroom.
K. Radioactive nuclei, II. Terrace.
KA. Metals. Panel.
L. Theoretical physics, IV. Boston Room.

Wednesday Morning

M. Symposium on biophysics: Gamow, Wyckoff, Pollard, Failla. Terrace.
MA. Semiconductors, I. Manhattan Center, Gold Room.
N. Magnetism; ferroelectricity; postdeadline papers, if any. Panel.
NA. Pugh, Oxley, Hofstadter, Felt, Slepian. Grand Ballroom.
P. Theoretical physics, V. Boston Room.

Wednesday Afternoon

Q. *K*-mesons: R. W. Birge, Ritson, Fitch, Orear. Grand Ballroom.
QA. Semiconductors, II. Manhattan Center, Gold Room.
R. Neutron physics, I. Panel.
RA. Morse, Schultz, Pauli. Terrace.
S. Hatton; cryogenics. Boston Room.

Wednesday Evening at 7:30

Banquet of the American Institute of Physics.
Grand Ballroom. Rabi, Schweitzer.

Thursday Morning

T. Joint ceremonial session of APS and AAPT: Birge, Brattain, Uhlenbeck. Manhattan Center.

Thursday Afternoon

TA. Programme of American Institute of Physics: Stratton, Casimir, Oppenheimer. Manhattan Center.

Friday Morning

U. Accelerators. Grand Ballroom.
UA. Neutron physics, II. Panel.
V. Heavy mesons and hyperons; cosmic rays. Terrace.
VA. Geballe, Bean, Pines, H. P. Kallmann. Boston Room.
W. Theoretical physics, VI. Empire.
WA. Division of High-Polymer Physics and Society of Rheology: rheology of polymers: Tobolsky, Zimm, Ferry, Watkins. Manhattan Center, Gold Room.

Friday Afternoon at 1:45

Business Meeting of the American Physical Society. Grand Ballroom.

Friday Afternoon at 2:45

X. Rheology of polymers, concluded: Blatz, Rivlin, Mooney, Lee. Manhattan Center, Gold Room.
XA. Apparatus of nuclear physics; positronium; Ridgway. Terrace.
Y. Neutron physics, III. Panel.
Z. Mesons. Grand Ballroom.
ZA. Theoretical physics, VII. Boston Room.

PROGRAMME

MONDAY MORNING AT 10:00

Grand Ballroom

(E. SEGRÈ presiding)

Fission

A1. Variation in ν the Number of Neutrons Emitted per Fission in the Thermal Energy Region.* R. L. ZIMMERMAN, H. PALEVSKY, AND D. J. HUGHES, *Brookhaven National Laboratory.*—A comparison of the directly measured[1] energy variation of η, the neutron multiplication, to the same variation calculated from the total and fission cross section measurements showed that for U^{233} and U^{235} the data are consistent with the usual assumption that ν is a constant in the thermal energy region. In the case of Pu^{239}, however, a disagreement between the directly observed and calculated value of η was found. The plutonium measurements were therefore extended using the fast chopper, through the resonance at 0.3 ev up to 0.5 ev and overlapping the slow chopper measurements.[1] The results indicated a value of ν at 0.3 ev some 12% less than at thermal. In order to further verify whether ν changes with energy the apparatus was modified in order to measure conicidences between pairs of fission neutrons. The ratio of coincidence to single counts in such an experiment is proportional to ν. A variation in ν was found that is in agreement with that deduced from the cross section and η results. Because of the importance of such an effect to the understanding of the fission process a third measurement is now underway to measure ν in a more direct manner.

* Work performed under contract with U. S. Atomic Energy Commission.
[1] Palevsky, Zimmerman, Eisberg, and Hughes, Phys. Rev. **100**, 1266(A) (1955).

A2. Search for a Variation of $\bar{\nu}$ with Slow Neutron Energy. B. R. LEONARD, JR., E. J. SEPPI, and W. J. FRIESEN, *General Electric Company, Richland.*—The possibility that the value of $\bar{\nu}$, the average number of fast neutrons emitted per slow neutron fission, varies with the energy of the incident neutron has been investigated. The neutron crystal spectrometer has been used to obtain monoenergetic neutrons to investigate the behavior of $\bar{\nu}$ from thermal neutron energies through the first fission resonance for U^{235} and Pu^{239}. The relative values of $\bar{\nu}$ were obtained from the ratio of the fast neutron emission rate from a source foil of fissionable material to the fission rate measured with another foil in a thin window fission fragment ionization chamber in the same neturon beam. A Zn−S(Ag)-Lucite scintillator was used for fast neutron detection. Corrections were applied for attenuation and scattering of the neutron beam in the source foil. For U^{235} nine energy points were measured from 0.025 to 0.40 ev. The relative values obtained for $\bar{\nu}$ had a rmp deviation from the mean of 0.36 percent. Preliminary results obtained with Pu^{239} also indicate a constant value of $\bar{\nu}$ for the same energy region but inconsistencies obtained in these data limit the precision of the result to several percent.

A3. Energy Distribution of Mass-97 Fragments from Thermal Neutron Fission of U^{235}. B. L. COHEN, A. F. COHEN, AND H. G. BLOSSER, *Oak Ridge National Laboratory.*—A high-resolution spectrograph has been constructed for measurements of $H\rho$ distributions of fission fragments of a given mass. The fragments originate in a thin strip of U^{235} near the center of the ORNL Graphite Reactor, come through a 16-ft tube to a wedge magnet outside the reactor shield, are magnetically analyzed, and strike an aluminum foil placed in the focal plane. After a time, the foil is removed and cut into strips with each strip corresponding to a given $H\rho$; these are radiochemically processed for a given product element, thus determining the fragment mass (in all work to date, Zr^{97} was used), and counted under end-window Geiger counters. The over-all energy resolution of the spectrograph is 0.8%. Operating the system at high vacuum, a broad continuous $H\rho$ distribution is obtained with width corresponding to fragment charges 18 to 23. Within the accuracy of preliminary experiments, this curve exhibits no fine structure between adjacent charges; this indicates that the energy distribution has a width of at least 8%. Several auxiliary experiments have been undertaken to determine this distribution more accurately; very preliminary results indicate an energy spread not much wider than the aforementioned.

A4. Correlation between Average Number of Prompt Neutrons and Total Kinetic Energy of Fragments in Spontaneous Fission of Californium-252.* DONALD A. HICKS, JOHN ISE, JR., ROBERT V. PYLE, AND GREGORY R. CHOPPIN. *University of California, Berkeley.*—The average number of prompt neutrons has been correlated with the total kinetic energy of the fission fragments in the spontaneous fission of californium-252. The active material was vaporized onto a collimated 5-$\mu g/cm^2$ VYNS foil and placed as the common cathode in a "back-to-back" fission chamber, which was located at the center of a large cadmium-loaded liquid scintillator tank. The experimental method was similar to that used in the determination of the prompt neutron-emission probabilities[1] except that the pulse heights of the two complementary fission fragments also were recorded. With only a portion of the data analyzed, the total fragment-energy curve has been divided up into 16-Mev bites, but no corrections have been made for ionization defect or instrumental resolution (about ±10 Mev). Preliminary results are:

Total kinetic energy range (Mev)	105–121	121–137	137–153	153–169	169–185
Average number of prompt neutrons per fission (standard errors shown)	4.1 ±0.4	4.5 ±0.3	4.1 ±0.2	3.4 ±0.2	2.3 ±0.3

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] Hicks, Ise, and Pyle, Phys. Rev. **98**, 1521 (1955).

A5. Fission Cross Section of U^{235} from 2 to 100 ev. M. L. YEATER, W. R. MILLS, D. E. MCMILLAN, AND E. R. GAERTTNER, *Knolls Atomic Power Laboratory.**—The KAPL neutron velocity selector[1] is being used with a large multiplate fission chamber to measure the fission cross section of U^{235}, in the energy range from 2 to 100 ev. The data will be compared with past fission measurements taken with lower resolution and also with recent total cross-section measurements.[2] Fission width and capture-to-fission ratios for some of the stronger levels will also be presented.

* Operated for the U. S. Atomic Energy Commission by the General Electric Company.
[1] Yeater, Gaerttner, and Baldwin, Phys. Rev. **91**, 451(A) (1954).
[2] BNL-325.

Invited Papers on the Antiproton

Introductory Remarks by the Chairman

A6. The Antiproton. OWEN CHAMBERLAIN, *University of California, Berkeley.* (30 min.)

A7. Charge Conjugation and Nucleon-Antinucleon Systems. T. D. LEE, *Columbia University.* (30 min.)

MONDAY MORNING AT 10:00

Panel Room

(R. HOFSTADTER presiding)

Nuclear and Electronic Scattering; Diverse Topics

AB1. Depolarization in $\bar{p}-p$ Scattering at 415 Mev.* J. A. KANE, R. A. STALLWOOD, R. B. SUTTON, AND J. G. FOX, *Carnegie Institute of Technology.*—The depolarization parameter $D(\theta)$ defined by Wolfenstein[1] has been measured at c.m. angles of 54°, 73°, and 90°. A 53% polarized beam was incident upon a liquid hydrogen target. The polarization of the scattered flux was measured by a carbon target and counter telescope arrangement. Compounding the results at angles θ and $-\theta$ gave the product $D(\theta)P_3(\theta)$, where $P_3(\theta)$ is the asymmetry measured by the analyzer for 100% polarized flux and was measured by analyzing a beam of known polarization of an energy appropriate to θ. Our results, which are similar to the 310-Mev results of the Berkeley group,[2] give $D=0.42\pm0.09$ at $\theta=90°$ c.m. This places an upper limit of about 60% on the amount of singlet scattering at 90°.

* This work supported by the U. S. Atomic Energy Commission.
[1] L. Wolfenstein, Phys. Rev. **96**, 1654 (1954).
[2] T. J. Ypsilantis, University of California Radiation Laboratory Report 3047.

AB2. Scattering of 7.5-Mev Protons by He^4.† T. M. PUTNAM, J. E. BROLLEY, JR., AND LOUIS ROSEN, *Los Alamos Scientific Laboratory.*—The differential cross section for elastic scattering of 7.5-Mev protons by He^4 has been measured using the proton beam from the Los Alamos variable energy cyclotron. Measurements were made at 31 angles between 10° and 172.5°, with nuclear emulsions in the Los Alamos nuclear multiplate camera.[1] The proton beam entered the scattering chamber after passing through a set of magnetic quadrupole focusing lenses, a 30° analyzing magnet, and a set of collimating apertures. This system gave a resultant energy spread of less than 50 kv and an angular divergence of the order of ±0.2°. Approximately 100 000 tracks were counted. The standard error of the preliminary results is ±2.7%. A phase-shift analysis of the data by Dr. J. L. Gammel gives: $\delta_0=-57°\ 13.1'$, $\delta_1{}^+=108°\ 10.2'$, $\delta_1{}^-=48°\ 11.5'$, $\delta_2{}^+=-0°\ 22.2'$, $\delta_2{}^-=-2°\ 20'$. These phase shifts fit the data within the experimental uncertainties and are in good agreement with those determined from experiments at other energies.[2–4]

† Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Allred, Rosen, Tallmadge, and Williams, Rev. Sci. Instr. **22**, 191 (1951).
[2] C. L. Critchfield and D. C. Dodder, Phys. Rev. **76**, 602 (1949).
[3] D. C. Dodder and J. L. Gammel, Phys. Rev. **88**, 520 (1952).
[4] Sack, Biedenharn, and Breit, Phys. Rev. **93**, 321 (1953).

AB3. Elastic Scattering of Protons from C^{13}.† D. ZIPOY, K. FAMULARO, AND G. D. FREIER, *University of Minnesota.*—An extension of the measurement of differential scattering cross sections[1] for $C^{13}(p,p)C^{13}$ was carried out over an energy range from 1.5 to 3.4 Mev. The angles used were: 45°, 54.4°, 74.1°, 90°, 106.4°, 127.8° and 148.9° in the center-of-mass system. Methane gas, made from methyl iodide was used as a target; the sample was enriched to 72.5% $C^{13}H_4$. The resulting cross sections were accurate to about 5% except in the region of a resonance in elastic scattering from C^{12} (at about 1.7 Mev[2]). In the neighborhood of this energy, the errors contributed by the subtraction of the C^{12} yields made it impossible to observe any resonance which might be due to the 9.18-Mev level in N^{14}.[3] Prominent maxima in cross sections were observed at incident proton energies of 1.99, 2.12, 2.33, 2.96, and 3.11 Mev.

† Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] E. M. Milne, Phys. Rev. **93**, 762 (1954).
[2] Jackson, Galonsky, Epping, Hill, Goldberg, and Cameron, Phys. Rev. **89**, 365 (1953).
[3] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **27**, 125 (1955).

AB4. Polarization of 220-Mev Protons Elastically Scattered from Carbon.* W. G. CHESNUT, E. M. HAFNER, AND A. ROBERTS, *University of Rochester.*—Measurements of the polarization produced by elastic scattering of 220-Mev protons from C^{12}, preliminary results of which have already been reported,[1] have been refined and extended. Data are now available in the range of 4° to 40° with an angular resolution of ±1.5°. A more complete study of the effects of inelastic scattering has been carried out. Three *extrema* of ϵ *versus* θ are now clearly established. The first, a maximum, occurs at about 16°; the third, also a maximum, occurs at about 35°. The second, a minimum which had been zero or slightly positive in earlier measurements with greater angular acceptance, is now seen to be negative. This minimum occurs at about 27°. Theoretical consequences of this and other new results including Coulomb effects will be given.

* Work supported by the U. S. Atomic Energy Commission.
[1] Chesnut, Hafner, and Harding, Phys. Rev. **99**, 639(A) (1955).

AB5. Scattering of 187-Mev Electrons from Carbon.* J. H. FREGEAU, *Stanford University.*—The scattering of 187-Mev electrons from carbon, reported previously,[1] has been extended to larger angles. Measurements of the elastic scattering cross section and the cross section for inelastic scattering corresponding to the 4.43-Mev excited state have been extended to 138° (the present limit of the equipment). The absolute values have been obtained by comparison with previous results. The angular distribution of the 4.43-Mev scattering falls off less rapidly with increasing angle than the elastic scattering. At angles greater than ~90°, the inelastic scattering of the 4.43-Mev level is larger than the elastic. For example, at 130° the elastic scattering is 4.3×10^{-34} cm²/sterad while the 4.43-Mev scattering is 6.7×10^{-33} cm²/sterad. Some measurements have also been made of the inelastic scattering corresponding to the 7.65-Mev and 9.61-Mev excited states.

* Supported jointly by the Office of Naval Research and the U. S. Atomic Energy Commission, and by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command. Also aided by a grant from the Research Corporation.
[1] J. H. Fregeau and R. Hofstadter, Phys. Rev. **99**, 1503 (1955).

AB6. High-Energy Electron Scattering and the Electrodisintegration of the Alpha Particle.*† R. BLANKENBECLER AND R. HOFSTADTER, *Stanford University.*—With the new semicircular double-focusing magnetic spectrometer, electron scattering has been observed from helium gas at high pressure. At an energy of 400 Mev in the incident beam the elastic scattering has been studied at angles between 45° and 70° in the laboratory frame. Besides the sharp elastic peaks, prominent inelastic continua have been observed at several angles. At a given scattering angle the inelastic continuum shows a strong peak at an energy approximately 20 Mev below the position corresponding to scattering from the free proton. The inelastic continua also exhibit thresholds about 20 Mev below the elastic scattering peaks of the alpha particle, corresponding to the ejection of a single particle from the alpha particle. Theoretical treatment of the elastic data furnishes new information on the size and shape of the alpha particle. Preliminary analysis using the Born approximation gives an rms charge radius of 1.55×10^{-13} cm if the shape is Gaussian and 1.40×10^{-13} if a uniform shape is assumed. The best fit lies in between these models. The new data are thus in excellent agreement with an earlier determination.[1]

* The research reported here was supported jointly by the Office of Naval Research, the U. S. Atomic Energy Commission, and the Office of Scientific Research of the U. S. Air Force.
† Aided by a grant from the Research Corporation.
[1] Hofstadter, McAllister, and Wiener, Phys. Rev. **96**, 854 (1954).

AB7. New Data on the Structure of the Proton.*† R. HOFSTADTER AND E. E. CHAMBERS,‡ *Stanford University.*—A new semicircular double-focusing magnetic spectrometer with 36-in. radius of curvature has recently been placed in operation at electron energies up to 400 Mev. Detection of the scattered electrons after magnetic deflection is accomplished with a Čerenkov counter enclosed within a ten-ton shield located on the magnet and moving with it. Sharp elastic peaks corresponding to electrons scattered from protons in polyethylene are observed at energies and angles consisent with relativistic kinematics. The areas under such peaks are measured as a function of scattering angle. As observed previously at lower energies[1] the cross section falls below the scattering expected from a point proton and (subject to the validity of the Coulomb law) indicates that the proton has a diffuse structure. By fitting the observed cross section with a phenomenological form factor corresponding to exponential charge and magnetic moment distributions a proton size can be determined. Preliminary values are $r_e=r_m=8\times10^{-14}$ cm where r_e and r_m are, respectively, rms radii of charge and magnetic moment distributions. These results are in excellent agreement with the earlier determinations.[1]

* The research reported here was supported jointly by the Office of Naval Research, the U. S. Atomic Energy Commission, and the Office of Scientific Research of the U. S. Air Force.
† Aided by a grant from the Research Corporation.
‡ Lieutenant, U. S. Coast Guard.
[1] R. Hofstadter and R. W. McAllister, Phys. Rev. **98**, 217 (1955).

AB8. Polarization Measurements for 1-Mev Bremsstrahlung.* J. W. MOTZ, *National Bureau of Standards.*—With 1-Mev electrons incident on thin targets of aluminum and gold, the polarization of the bremsstrahlung emitted at 20 degrees with respect to the initial electron direction has been detected. The polarimeter ultilizes the polarization sensitivity of the Comption process and consists of a double crystal Compton spectromerer[1] with anthracene as a scatterer and NaI(Tl) as a detector for photons scattered at approximately 80 degrees.[2] For selected photon energies in the range from 0.2 to 1.0 Mev, measurements with the NaI crystal at different azimuths about the x-ray beam are evaluated in terms of polarization by means of Compton scattering theory.[3] The results show a reversal of polarization along the spectrum in qualitative agreement with the Born-approximation theory.[4] However there are discrepancies with regard to the quantitative features of the theory.

*Work supported by the U. S. Atomic Energy Commission.
[1] R. Hofstadter and J. McIntyre, Phys. Rev. **78**, 619 (1950).
[2] F. Metzger and M. Deutsch, Phys. Rev. **78**, 551 (1950).
[3] See for example U. Fano, J. Apt. Soc. Am. **39**, 859 (1949); Phys. Rev. **93**, 121 (1954).
[4] R. L. Gluckstern and M. H. Hull, Jr., Phys. Rev. **90**, 1030 (1953).

AB9. Experimental Energy and Angle Distributions of Thin-Target Bremsstrahlung Produced by 2.5- to 10-Mev Electrons.—N. STARFELT AND H. W. KOCH, *National Bureau of Standards.*—The bremsstrahlung photons produced in thin targets by the removed electron beam from a betatron were examined with a 5-in. diameter by 9-in. long sodium iodide spectrometer and a thirty-channel pulse-height analyzer. Pulse-height distributions were obtained for x-rays whose energies were above 200 kev. Approximately 50 000 counts were recorded in each distribution for an incident electron energy of 2.7, 4.5, or 9.7 Mev at angles between 0° and 6°. The targets were 2630 μg/cm² Be, 880 μg/cm² Al, and 210 μg/cm² Au. The results when compared with the calculations of Gluckstern and Hull[1] show that the aluminum spectra at 0° agree to better than 10% at most photon energies. The experimental differential cross sections are higher than theory for gold, and differences as large as 100% occur for the higher photon energies and the larger angles. Evaluation of the beryllium data is difficult because of our inability to correct accurately for the electron-electron bremsstrahlung. Thick target tungsten data were also obtained for 4.5 and 9.7 Mev.

[1] R. L. Gluckstern and M. H. Hull, Phys. Rev. **90**, 1030 (1953).

AB10. Penetration of Gamma Radiation through Very Thick Absorbers. EDWIN J. SCHILLINGER, JR., AND MICHAEL SVONAVEC,* *De Paul University.*—The intensities of gamma radiation from Co^{60} as a function of penetration through very thick (up to 20 inches) absorbers of iron and lead have been calculated on the basis of multiple scattering.[1] Normal incidence of a wide homogeneous beam upon a flat surface was assumed and Klein-Nishina scattering only was considered. These calculated results are in complete agreement with interpolations of Hirschfelder's results. An experimental verification of predicted intensities is in progress. The ideal geometry of a point detector and wide beam cannot be achieved. We have, therefore, employed a narrow beam and have scanned the radiation field behind the absorber. An approximate integration of the total intensity is made simple since the intensity distribution appears nearly Gaussian. Preliminary data, using weak (10 mc) sources indicate agreement with predicted behavior. Data taken using a 1-curie Co^{60} source will be presented.

* Now at Armour Research Foundation.
[1] Hirschfelder, Magee, and Hull, Phys. Rev. **73**, 852 (1948); G. O. Hirschfelder and E. N. Adams, Phys. Rev. **73**, 863 (1948).

AB11. Double Compton Effect. L. A. BEACH AND R. B. THEUS, *U. S. Naval Research Laboratory.*—The angular correlation of two gamma rays emitted in a double Compton process has been observed with a coincidence scintillation spectrometer. Gamma rays from a collimated 20-curie source of Co^{60} were scattered by a 0.5-g/cm² carbon slab into two 1 in.×$\frac{1}{4}$ in. NaI(Tl) detectors. The fast coincident analyzer has a time resolution of 10^{-8} sec. Only those coincident events were selected in which the energy of one gamma was much larger than the other. The counting rate at a scattering angle of 60° as a function of the azimuthal angle between the detectors agrees after correction for background effects with the approximate distribution calculated by Mandl and Skyrme.[1] The exact angular distributions of the double Compton effect have been evaluated on the NAREC and agree in magnitude and angular variations with the distributions of Mandl and Skyrme.

[1] Mandl and Skyrme, Proc. Roy. Soc. (London) **A215**, 497 (1952).

MONDAY MORNING AT 10:00

Terrace Room

(E. M. PURCELL presiding)

Magnetic Resonance and Allied Topics

B1. Overhauser Nuclear Polarization Effect. W. A. BARKER AND A. MENCHER, *St. Louis University and Swiss Federal Institute of Technology.*—The thermodynamics of irreversible processes[1] has been used to derive expressions for the nuclear polarization under conditions of electron spin saturation[2] for both metals and nonconducting paramagnetics. Three general types of nuclear spin relaxation are considered.[3] The results may be interpreted in terms of electronic and nuclear spin temperature.

[1] S. R. de Groot, *Thermodynamics of Irreversible Processes* (Interscience Publishers, Inc., New York, 1952).
[2] A. W. Overhauser, Phys. Rev. **92**, 411 (1953).
[3] W. A. Barker and A. Mencher, Phys. Rev. **98**, 1868 (1955); Phys. Rev. (to be published).

B2. Magnetic Resonance and the Principle of Minimum Entropy Production. ROALD K. WANGSNESS, *U. S. Naval Ordnance Laboratory.*—It can be shown by statistical mechanical methods that in the steady state attained by a system of magnetic moments in a resonance experiment the rate of entropy production is a minimum and equal to the rate at which energy is absorbed by the spin system and transferred to the heat bath divided by the temperature of the bath. It is assumed that the external field has a circularly polarized component perpendicular to a constant component, and that the contact between the spin system and the heat bath is provided only by strong collisions. In this case, the effects of the external field can be taken into account exactly so that the relative amplitudes of the rotating and constant fields need not be restricted as is the case when formulated in terms of transition probabilities.[1] Because of the coherent relations among the phases of the probability amplitudes, the average off-diagonal elements of the density matrix do not vanish in this case, and it is necessary to extend the usual statistical mechanical definition of entropy to include terms involving these elements.

[1] M. J. Klein, Phys. Rev. **98**, 1736 (1955).

B3. A General Formula for the Nuclear Alignment Coefficient. J. H. VAN VLECK, *Harvard University.*—The coefficient Δ defined by $\Delta=\langle 3I_z^3-I(I+1)\rangle_{Av}/3I^3$ measures the nuclear alignment which results[1] when $H\neq 0$ and/or when $A\neq B$ in the hyperfine interaction $AS_xI_x+B(S_xI_x+S_yI_y)$. The Zeeman member of the Hamiltonian we take to be $g_\parallel\beta HS_z$. We show that, with this model,

$$\Delta=\frac{(I+1)(2I+3)(2I-1)}{90g_\parallel^2\beta^2kTI}\left[\left(\frac{\partial M}{\partial H}+\frac{M^2}{kT}\right)A^2-\chi_\perp\frac{g_\parallel^2}{g_\perp^2}\right]$$

quite generally to terms of the second order in A/kT, B/kT, regardless of the amount of crystalline field or interatomic coupling (except for nuclear quadrupole potentials, which we neglect). This formula eliminates elaborate perturbation calculations if the electronic magnetic moment M and perpendicular susceptibility $\chi_\perp$ per atom are known either theoretically or experimentally as a function of H. Generalization is readily made to the completely anisotropic case with no axis of symmetry.

[1] See, for instance, N. R. Sternberg, Phys. Rev. **93**, 678 (1954).

B4. Effect of Hydrostatic Pressure on the Nuclear Quadrupole Coupling in Crystalline Fields.* G. B. BENEDEK, N. BLOEMBERGEN, AND T. KUSHIDA, *Harvard University.*—The pure quadrupole resonance of Cu^{63} in a powdered sample of cuprous oxide[1] suspended in kerosene has been observed as a function of pressure in the range 1–10 000 atmospheres. The pressure equipment was similar to that used by Benedek.[2] The resonance line did not broaden noticeably, but about 60% of intensity was lost at the highest pressure. The deformation is very homogeneous in some crystallites but presumably inhomogeneous deformations broaden the line beyond observation in others. The resonance frequency varied linearly with pressure, and the pressure coefficient of the electric field gradient is $(\partial q/\partial P)q^{-1}=(1.37\pm0.01)\times10^{-6}/\text{kg/cm}^2$. For the Cl^{35} resonance[3] in $NaClO_3$ this coefficient is $(0.93\pm0.01)\times10^{-6}/\text{kg/cm}^2$. These data will be compared with the known temperature coefficient of q, the compressibility and thermal expansion of these crystals.

* Research supported under Office of Naval Research.
[1] H. Krüger and U. Meyer-Berkhout, Z. Physik **132**, 171 (1952).
[2] G. B. Benedek and E. M. Purcell, J. Chem. Phys. **22**, 2003 (1954).
[3] T. C. Wang, thesis, Columbia University, 1955 (unpublished).

B5. As^{75} Pure Quadrupole Resonance in Claudetite. P. J. BRAY*† AND GEORGE O'KEEFE, *Rensselaer Polytechnic Institute,* AND R. G. BARNES,‡ *University of Delaware.*—The As^{75} pure quadrupole resonance in claudetite, the high temperature monoclinic form of arsenic trioxide has been detected and measured as a function of temperature. The frequencies are: 110.909 ± 0.015 Mcps at 77°K; 109.898 ± 0.045 Mcps at 195°K; and 108.601 ± 0.028 Mcps at 32°C. These frequencies are only 6 to 8 Mcps lower than the values found in arsenolite,[1] the cubic low-temperature modification of the material. The structure of claudetite has been determined by Frueh.[2] Although the distinct As_4O_6 molecules existing in arsenolite are not present, the compound can be considered as AsO_3 groups linked together through the oxygens. The bond lengths and angles are sufficiently similar to those in arsenolite to explain the relatively small difference in frequency for the two forms of the mineral. The temperature dependence of the resonance frequency is approximately four times as great in claudetite, however.

* Now at Brown University, Providence, Rhode Island.
† Research supported by a grant from the National Science Foundation.
‡ Research supported by the Office of Ordnance Research.
[1] H. Krüger and U. Meyer-Berkhout, Z. Physik **132**, 221 (1952).
[2] A. J. Frueh, Jr., Am. Mineral. **36**, 833 (1951).

B6. Pure Quadrupole Line Shapes in Solid Iodine. G. D. WATKINS AND R. M. WALKER, *General Electric Research Laboratory.*—Studies of pure quadrupole resonance line widths *vs* temperature in cold-worked iodine crystals indicate that diffusional narrowing of the strain-broadened line takes place. This is interpreted as vacancy diffusion of iodine molecules in the solid lattice. At room temperature the narrowing is sufficient to reveal partially resolved structure in the 330-mcps line. The direct magnetic dipole-dipole interaction between the two nuclei of a molecule is an order of magnitude too small to account for the structure. However, either a contact type $A\mathbf{I}_1\cdot\mathbf{I}_2$ or a pseudodipole-dipole interaction via the bonding electrons can produce the effect. The value of A required is -2.4 kcps. Attempts to resolve structure in the high-frequency line have been unsuccessful.

B7. Magnetic Moment of the Neutron.* NOEL R. CORNGOLD AND VICTOR W. COHEN, *Brookhaven National Laboratory,* AND NORMAN F. RAMSEY, *Harvard University.*—We have

performed a resonance experiment on a beam of polarized neutrons and have measured the ratio of the Larmor precision frequencies of the neutron to that of the proton. The method used has been described previously.[1] The method of separated rf loops[2] permits extremely high resolving power for the neutron resonance. The limitation of accuracy appears to be associated with the measurement of the proton resonance frequency over the neutron trajectory in the magnetic field. Our measured ratio of resonant frequencies is $\nu_n/\nu_p = 0.685057$ with an estimated maximum error of 0.000016. This corresponds to a value of $\mu_n = 1.913150$ n.m.

* Work done at the Brookhaven National Laboratory under contract with the U. S. Atomic Energy Commission.
[1] Cohen, Corngold, and Ramsey, Bull. Am. Phys. Soc. (December, 1954).
[2] N. F. Ramsey, Phys. Rev. **78**, 695 (1950).

B8. Paramagnetic Resonances in Irradiated, Fused, and Crystalline Quartz. ROBERT A. WEEKS, *Oak Ridge National Laboratory.*—Paramagnetic resonances induced by irradiation with x-rays, γ rays, and neutrons in quartz, crystalline and fused, have been reported by a number of workers. We report here additional resonances in irradiated quartz of three varieties: vitreosil, Corning silica, and natural crystals. In the fused material two resonances are observed. One has an apparent g-value of 2.0011 ± 0.0005 and a width at the inflection points of ≈ 1 gauss. The other with a g-value of 2.010 ± 0.008 has a width at the inflection points of ≈ 15 gauss. A single crystal of irradiated quartz is observed to have a complex orientation-dependent group of lines. The number of lines clearly resolved varies from one to six when the crystal is rotated about the a-axis perpendicular to the magnetic field direction. The range of g-values for the lines is 2.0006 to 2.0028. The resonance observed in a powdered specimen of one of the crystals is identical to the resonance in the Corning silica and vitreosil with respect to shape, width, and g-value. It is suggested that these resonances in the three materials arise from the same source and do not arise from impurities. These resonances apparently have no relation to the ones reported by Griffith *et al.*[1]

[1] Griffiths, Owen, and Ward, Report of the Conference on Defects in Crystalline Solids, Physical Society (London) p. 81–91 (July, 1955).

B9. Resolved Hyperfine Structfire in *F*-Center Spin Resonance.* N. W. LOPD AND C. K. JEN, *Applied Physics Laboratory.*—Continuing earlier work[1] in the microwave magnetic resonance of color centers, we have detected a partially resolved hyperfine structure in neutron-irradiated LiF single crystals. The hyperfine components appear as uniformly spaced sharp variations superposed on a broad resonance derivative curve when a small modulation field is used. The separation between any two adjacent components is 14.1 ± 0.3 oersteds. Under good resolution, the number of components having decreasing intensity from the center component is clearly countable up to 17 with possibly a few more mixed in noise. The g-factor of the center component is 2.0037 ± 0.0011. On the basis of comparative studies of optical and magnetic spectra, we believe the observed hyperfine structure is due to *F*-center spin resonance. This identification is consistent with the theoretical expectations of the deBoer model of the *F*-center electron interacting with its neighboring nuclei, resulting in 19 hyperfine components for the present case. On the other hand, the observed hyperfine structure can be theoretically attributed to *F*-centers on the interstitial atom model only under very unlikely assumptions.

* This work supported by the Bureau of Ordnance, Department of the Navy.
[1] C. K. Jen and N. W. Lord, Phys. Rev. **96**, 1150 (1954).

B10. Multiple Ferromagnetic Resonance Absorption in Manganese and Manganese-Zinc Ferrite. R. L. WHITE, I. H. SOLT, JR., AND J. E. MERCEREAU, *Hughes Research Laboratories.*—Ferromagnetic resonance experiments have been performed on single crystal spheres of manganese and manganese-zinc ferrites placed in field configurations having large gradients in the rf magnetic field at the sample site. Five major and several minor resonant absorptions are observed extending over a region of 700 gauss at room temperature. The individual line widths are approximately 25 gauss for manganese ferrite and 23 gauss for manganese-zinc ferrite. The component lines may be excited separately or in subgroups by selecting field configurations of proper symmetry. The line intervals are nearly independent of sphere diameter over the range 0.235 mm to 1.33 mm, and of frequency over the range 8.1 kmc to 9.9 kmc but are a strong, fairly complicated function of temperature. In this experiment, in contrast to the conventional ferromagnetic resonance experiment, the direction or amplitude of the driving microwave field is varied across the sample, causing a spatial variation in the spin precessional phase. A simplified model is proposed in which the sphere oscillates in halves or quadrants. The characteristic roots of the appropriate coupled oscillator problem have both the proper symmetry of normal coordinates and proper dependence on coupling strength (temperature) to describe the main features of the spectrum.

MONDAY MORNING AT 10:00

Empire Room

(M. W. P. STRANDBERG presiding)

Microwave and Band Spectra

BA1. Microwave Spectrum, Structure, Quadrupole Coupling Constants, and Dipole Moment of Formamide.* ROBERT J. KURLAND,† *Harvard University.*‡—The structural parameters, quadrupole coupling constants, and dipole moment of formamide have been determined from rotational transitions of H_2NCHO and the isotopically substituted species D_2NCHO, DHNCHO (*cis*), and DHNCHO (*trans*) observed in the microwave region. The structural parameters are C–O, 1.243 ± 0.007 A; C–N, 1.343 ± 0.007A; N–H, 0.995 ± 0.007 A; HNH, $118.98 \pm 0.50°$; NCO, $123.58 \pm 0.35°$; NCH, $103.9 \pm 1.2°$. The planarity relationship is satisfied for the moments of inertia of H_2NCHO to within a small inertial defect: $I_a = 6.952$ a.m.u. A^2, $I_b = 44.448$ a.m.u. A^2, $I_c = 51.407$ a.m.u. A^2 and $\Delta = I_c - (I_b + I_a) = 0.007$ a.m.u.A^2. The quadrupole coupling constants are $\chi_a = 1.7$ mc, $\chi_b = 1.9$ mc and $\chi_c = -3.6$ mc. The magnitude of the dipole moment is 3.71 ± 0.03 D; the dipole moment is directed, as determined from the change in dipole moment components upon isotopic substitution and from considerations of typical bond moments, at an angle of 219.6° with respect to the C–N bond. The quadrupole coupling constants and C–N bond distance lead to the same estimate of π bonding between the nitrogen and carbon

atoms. The structural parameters and quadrupole coupling constants will be interpreted in terms of the bonding characteristic of formamide and related compounds containing the N−C−O linkage.

* Supported in part by the Office of Naval Research.
† General Electric Industrial Fellow, 1954–1955.
‡ Present address: National Bureau of Standards.

BA2. ND_3 Inversion Spectrum.* GABRIEL HERRMANN,† *New York University.*—The inversion spectrum of ND_3 has been reinvestigated around 1600 Mc/sec. A revised formula for the rotational fine structure was obtained to fit 17 observed lines. Splitting of $K=3$ lines into A_1 and A_2 components were found in good agreement with predicted values. Nitrogen satellites were observed and the values $(eQq)_N=4080\pm3$ Kc and $a=2\pm2$ kc were obtained for the nitrogen quadrupole, and magnetic coupling constants, respectively. Hyperfine structure due to lifting of the K degeneracy by deuteron interactions was observed in $K=1$ lines. Applying the theory developed by Hadley,[1] and assuming cylindricalsymmetry about bonds, theoretical and experimental line contours were brought into agreement. The values $(eQq)_D=200\pm20$ kc and $B=1.9\pm0.5$ kc were obtained for the deuteron quadrupole coupling constant and the magnetic coupling constant between total deuteron spin and molecular rotation, respectively.

* Supported by the U. S. Air Force, through the Office of Scientific Research of the Air Research and Development Command.
† Now at Bell Telephone Laboratories, Inc., Murray Hill, New Jersey.
[1] G. F. Hadley, thesis, Harvard University (1955).

BA3. New Method for the Calculation of Stark Effect in Microwave Spectra.* CHUN C. LIN, *University of Oklahoma.*—A new procedure which is considerably simpler than the method of Golden and Wilson,[1] has been developed for the calculation of the Stark effect of the rotational transitions for an asymmetric top. The Hamiltonian matrix is first constructed in the symmetric top representation and a van Vleck transformation is then applied to remove the elements nondiagonal in J arising from the effect of the electric field. Through this transformation the Stark terms are incorporated into the $(K|K)$ and $(K|K\pm2)$ elements of the rigid rotor matrix, and hence can be considered to produce a slight modification of the rotational constants. The Stark effect is then obtained by comparing the energy levels of two rigid rotors with slightly different moments of inertia. For slightly asymmetric tops the Stark coefficients can be calculated easily with the aid of the tabulated coefficients[2] for the expansion of the energy levels in terms of Wang's parameter.

* The major part of this work was done at Mallinckrodt Laboratories, Harvard University and was supported by the Office of Naval Research.
[1] S. Golden and E. B. Wilson, Jr., J. Chem. **16**, 669 (1948).
[2] C. H. Townes and A. L. Schawlow, *Microwave Spectroscopy* (McGraw-Hill Book Company, Inc., New York, 1955), p. 522.

BA4. Nuclear Quadrupole Interactions in the Microwave Spectra of Internally Rotating Molecules. DAVID R. LIDE, JR., *National Bureau of Standards.*—The numerous observations of nuclear quadrupole hyperfine structure in microwave spectra have been satisfactorily analyzed on the basis of the rigid-rotor theory. It is pointed out that modifications of this theory may be necessary in the case of molecules which are capable of internal rotation. The procedure for including quadrupole terms in the computation of rotational energy levels is indicated. It is shown that internal rotation does not affect the hyperfine structure in symmetric rotors. In methanol and nitromethane-type molecules the effects are generally small but may be quite large if near degeneracies occur. In particular, the hyperfine splitting of certain levels with $K=1$ may, in some circumstances, be a sensitive function of the internal potential barrier. From a physical viewpoint the internal rotation may be considered to smear out the asymmetry in the electric field gradient at the quadrupolar nucleus. Several nolecules in which such effects could occur will be discussed.

BA5. Low-Frequency *l*-Type Doubling Spectrum of HCN.* LEONARD YARMUS, *N. Y. U.*—Direct l-type transitions for $J=3$, 4, and 5 have been observed with a Stark-modulated spectrometer. The measured frequencies are in fair agreement with the Westerkamp formula.[1,2] The eQq for N^{14} was found to be -4.80 ± 0.02 mcps, which is five percent higher than that found previously[3] in the ground vibrational state. Values of $\eta eQq=396\pm24$ kc and $c_l=13\pm5$ kc, where η and c_l are the asymmetry parameter and magnetic coupling constant, respectively, were found, and these are in good agreement with the work of White.[4,5] A search will be made for the $J=1$ and 2 lines.

* Supported by the U. S. Air Force, through the Office of Scientific Research of the Air Research and Development Command.
[1] J. F. Westerkamp, Phys. Rev. **93**, 716 (1954).
[2] R. J. Collier, Phys. Rev. **95**, 1201 (1954).
[3] Simmons, Anderson, and Gordy, Phys. Rev. **77**, 77 (1950).
[4] R. L. White, J. Chem. Phys. **23**, 249 (1955).
[5] R. L. White, Revs. Modern Phys. **27**, 276 (1955).

BA6. Foreign Gas Pressure Broadening of OCS. K. L. PERKINS, A. V. BUSHKOVITCH, AND L. J. KIEFFER, *St. Louis University.*—Recent measurements performed at this University[1] gave the collision diameters for collisions of OCS with He, O_2, and N_2O to be 3.03, 5.00, and 7.42 A, respectively. The present work is an attempt to correlate these results with the theory of P. W. Anderson.[2] Calculations were made for the general cases of a linear polar molecule interacting with the following foreign molecules which include the above as special cases: monatomic, linear nonpolar, and linear polar. The interactions of importance seem to be the first-order London dispersion force for the first two cases and the combined dipole-quadrupole, quadrupole-quadrupole, and first-order dispersion forces in that order for the third case. In the case of OCS with He, O_2, and N_2O the calculations yield 3.22, 5.41, and 7.41 A, respectively, which appear to be in reasonable agreement with the experiment.[3] The investigation is presently being continued and extended to other types of molecules.

[1] Liuima, Bushkovitch, and Rouse, Phys. Rev. **96**, 434 (1954).
[2] P. W. Anderson, Phys. Rev. **76**, 647 (1949).
[3] Similar calculations have been made recently by W. V. Smith (private communication).

BA7. Spectroscopic Study of "Temperatures" Determined from OH, C_2, and CH Radicals in Low-Pressure Acetylene-Oxygen Flames.* D. F. HEATH AND H. P. BROIDA, *National Bureau of Standards.*—Rotational and vibrational "temperatures" from electronic transitions of OH, C_2, and CH radicals have been measured in detail as functions of position in low-pressure acetylene-oxygen flames. Pressures were varied from 1.6 to 6.0 mm Hg. Trends of temperature are presented as functions of mixture, pressure, position, mass flow rate, and burner size. Abnormalities in tempreature are discussed. Evidence is presented for the existence of a new "burning" region at the base of the flame. This region is about 1/10 the visible flame thickness and is characterized by strong emission of C_2 and CH relative to OH and by relatively high temperatures of C_2 and CH. Just above this region the OH rotational temperature is very high, about 9000°K.

* Supported by the Air Research and Development Command.

BA8. Microwave Determination of Carbon and Oxygen Mass Ratios.* B. ROSENBLUM AND A. H. NETHERCOT, JR., *Columbia University.*—Precision measurements of the $J=0\rightarrow1$ rotational transition in $C^{12}O^{16}$, $C^{13}O^{16}$, and $C^{12}O^{18}$ have been made in 120 000 Mc. Accurate atomic mass ratios can be determined from such measurements only if a correction to the moment of inertia of the molecule is made for the excitation of higher electronic states by the rotation of the molecule. It has

been shown[1,2] that this correction can be computed from the magnetic moment resulting from this rotation-electronic interaction. The magnetic moment of the CO molecule has been measured by comparison with the known magnetic moment of the arsenic nucleus in the molecule AsD_3. With this correction the C^{13}/C^{12} and O^{18}/O^{16} ratios were determined, and the results are in excellent agreement with nuclear reaction data.[3] The magnitude of the correction was approximately 20 parts per million. Work is in progress to further improve the accuracy of these measurements and to extend them to include C^{14} and O^{17}.

* Work supported jointly by the Signal Corps, the Office of Naval Research, the Air Research and Development Command, and the U. S. Atomic Energy Commission.

[1] M. W. P. Strandberg, *Microwave Spectroscopy* (Methuen and Company, Ltd., London, 1954).
[2] Townes and Schawlow, *Microwave Spectroscopy* (McGraw-Hill Book Company, Inc., New York, 1955) Chap. VIII.
[3] A. H. Wapstra, Physica XXI, 367 (1955).

BA9. Herzberg O_2 Bands in "Air" Afterglow.* CHARLES A. BARTH AND JOSEPH KAPLAN, *University of California.*—The Herzberg oxygen bands $^3\Sigma_u^+ \rightarrow {}^3\Sigma_g^-$ have been found in emission from "air" afterglows containing as much as 95% nitrogen. The gas is excited in a 60-mc, 1.5-kw electrodeless oscillator in a continuous flow system. It is argued that the reaction $O_3+N \rightarrow NO+O_2+5.4$ ev is mainly responsible for the O_2 emission with $O+O+M \rightarrow O_2+M+5.1$ ev becoming more important as the percentage of oxygen is increased. The atomic nitrogen-ozone reaction may also contribute to the airglow. The atmospheric bands of O_2 are also observed in this afterglow.

* Research supported by Geophysical Research Directorate, A. F. Cambridge Research Center.

BA10. Direct Measurement of Line Widths and Intensities in Carbon Monoxide at 2.35 Microns.* ARNOLD M. BASS AND HENRY J. KOSTKOWSKI, *National Bureau of Standards.*—The widths and intensities of absorption lines have been measured in the first overtone vibration-rotation band of carbon monoxide at 2.35 microns. Sufficiently high CO pressures were used so that direct measurements could be made with a grating spectrometer having a spectral slit width of about 0.3 cm^{-1}. Data were obtained at room temperature for a range of pressures from $\frac{1}{4}$ to 67 atmospheres and for path lengths from 5 to 750 mm. The direct measurements at 5 and 10 atmospheres were corrected by about 10% for the distortion effects of the finite spectrometer slit width.[1] The results obtained are discussed in terms of the line shape and the pressure dependence of line widths in CO and are compared with results obtained from the curve-of-growth method in this work and by others.[2]

* Supported in part by the U. S. Air Force, Air Research and Development Command.

[1] H. J. Kostkowski and A. M. Bass, J. Opt. Soc. Am. **45**, 900(A) (1955).
[2] W. S. Benedict and S. Silverman, Phys. Rev. **95**, 752(A) (1954).

MONDAY MORNING AT 10:00

Manhattan Center, Gold Room

(W. BLEAKNEY presiding)

Fluid Dynamics. I

C1. Electron Optical Study of Low Pressure Gas Flow.* L. MARTON, D. C. SCHUBERT, AND S. R. MIELCZAREK, *National Bureau of Standards.*—The spatial distribution of a gas in motion at an extremely low pressure is measured by an electron-optical Schlieren technique. A 1.8-kev electron beam is focused onto a Schlieren stop after having passed through the gas. Electrons which are scattered through small angles by the gas molecules will miss the stop and form a dark-field schlieren representation of the scattering gas. Thus the method provides a two-dimensional representation of the gas density in a single observation. In preliminary work, a record was made of the profile of a cadmium atomic beam at a mean density corresponding to 10^{-4} mm pressure. Plans for extension of the method to the measurement of the velocity distribution by time of flight methods will be discussed. This procedure will be applied to the measurement of accommodation coefficients of molecules reflected from solid surfaces.

* Work supported by the Office of Naval Research.

C2. Experimental Investigation of the Stability of Axially-Symmetric Poiseuille Flow.* RICHARD J. LEITE, *University of Michigan* (introduced by A. M. Kuethe).—Hot-wire measurements were made in fully-developed laminar flow in a smooth Lucite pipe having an internal diameter of 1.25 inches and a length of 73 feet at Reynolds numbers of 4000, 6600, and 13 000. Small, nearly-axially-symmetric disturbances were superimposed upon the mean flow by oscillating a small section of the inner wall of the pipe in the longitudinal direction. The frequency and amplitude of this motion could be continuously controlled over a suitable range of values. Radial traverses of the distrubed flow field gave amplitude and relative phase angle variations across the pipe while longitudinal surveys provided means of computing wave velocities and damping factors. A recently completed mathematical analysis of the problem by Corcos and Sellars (to be published) provided a source for comparison of results with theory. The wave velocities and damping factors obtained experimentally agreed satisfactorily with theoretical predictions. The flow proved to be stable to small disturbances in all cases investigated. A few observations were made of flow transition initiated by large disturbances.

* This research was supported by the United States Air Force, through the Office of Scientific Research of the Air Research and Development Command.

C3. Visualization of Low-Density Flows by Means of Oxygen Absorption of Ultraviolet Radiation.* P. M. SHERMAN, *University of California at Berkeley* (introduced by S. A. Schaaf).—The high absorption of ultraviolet radiation (1400 A–1500 A) by oxygen has been employed to obtain photographs of several flow configurations in the low density wind tunnel at Richmond. Attempts were made to determine the density distribution in axially symmetric rarefied gas flow from an analysis of the radiation absorbed as indicated by the photographs. A vacuum spectrograph-monochromator-camera with a 1470 A radiation source was adapted for installation in the wind tunnel. The photographs taken were of shock waves formed by flow over a sphere, a cone, wedges, and a cylinder

with axis aligned parallel to the direction of the flow. All photographs were taken at a free stream Mach number of approximately 3.9, with a uniform jet area of about two inches in diameter at the nozzle exit plane, and a tunnel test chamber static pressure of approximately 114 μ Hg. Limitations of the experimental procedure and density analysis are discussed.

* Supported by Wright Air Development Center.

C4. Acoustic Streaming and Forced Viscous Flow.* WESLEY L. NYBORG, *Brown University.*—*Acoustic streaming* is coming into use as the name for that field in acoustics-hydrodynamics which deals with steady circulatory motions set up by vibrating sources. The existing mathematical techniques for treating such problems are perturbation methods[1,2] in which the first approximation to the hydrodynamical equations gives the acoustic solution, while the second approximation gives the steady streaming. In the second approximation the nonlinear terms in the dynamical equation will, in general, have nonzero time averages. Once the time-averaged nonlinear terms are evaluated, the acoustic streaming problem is equivalent to a problem in steady viscous flow—that flow due to a body force distribution given by the nonlinear terms. For certain acoustic streaming problems the "equivalent body forces" are localized in small regions near a plane rigid boundary. Solutions for such problems may be built up from Lamb's result[3] for a force operative at a point in a viscous medium. Applications will be discussed.

* Supported jointly by the Office of Naval Research and the National Institutes of Health.
[1] Lord Rayleigh, Trans. Roy. Soc. (London) **175**, 1 (1884).
[2] C. Eckart, Phys. Rev. **75**, 68 (1948).
[3] H. Lamb, *Hydrodynamics* (Dover Publications, Inc., New York, 1945), p. 605 *ff*.

C5. Transonic Wave Drag of Smooth Bodies of Revolution.* PETER J. WESTERVELT, *Brown University* (introduced by R. B. Lindsay).—The wave drag on a smooth body of revolution moving at a speed near that of sound has been obtained by conventional acoustical methods. The passage of the body past fixed reference points is represented by a series of time dependent simple sources spaced one body length apart along the flight path. The acoustic power output of these sources divided by the velocity of the body yields the drag force. This naive approach is based on the fact that the finite amplitude wave dissipates itself rapidly in traveling one effective wavelength, this wavelength being roughly equal to the length of the body. Hence the linear array of transient sources, spaced one body length apart, may be considered to be noninteracting in the first approximation. The result of this analysis is a formula for D, the drag coefficient: $D=(2\pi S_0)^{-1}\langle(S')^2\rangle M$ in terms of M, the Mach number; the average value of the square of the derivative of S, the axial distribution of the cross-sectional area of the body; and S_0, the maximum cross-sectional area.

* This work was supported by the U. S. Air Force, Wright Air Development Center.

C6. Motion in a Resisting Medium. STANLEY WINKLER, *Army Electronic Proving Ground.*—The equation considered is

$$dp/dt=f(t,v,v^2),$$

where p is the momentum ($p=mv$), v is the velocity, and the mass, m, may vary with time. For certain functions, $f(t,v,v^2)$, solutions of the differential equation can be obtained in finite terms. The differential equation can arise in the discussion of the motion of a body in a medium whose resistance is proportional to the square of the velocity. If atmospheric resistance may be assumed proportional to the velocity squared, then a gliding airplane would be an example with constant mass and a rocket an example with not constant mass. This differential equation is a nonlinear first-order equation (Riccati equation) which can be transformed into a linear homogeneous differential equation of second order.

C7. Reflection of Pressure Waves from an Open End of a Duct.* GEORGE RUDINGER, *Cornell Aeronautical Laboratory.*—When pressure waves in a duct reach an open end, a three-dimensional wave pattern is established in the vicinity of the exit. These waves tend to adjust the exit pressure to the level it would have if the flow remained steady but further arriving waves continually modify the adjustment process. The instantaneous exit boundary conditions which determine the reflected waves depend therefore on the history of the flow. In the analysis of a nonsteady-flow problem by means of a wave diagram, this difficulty is customarily circumvented by the assumption that the exit pressure adjusts instantaneously to its steady-flow level. In the present investigation, the response of the exit pressure to an arbitrary incident wave was derived from the response to an incident shock wave[1] by means of a Duhamel integral. A general wave diagram procedure will be described which corrects the boundary conditions at any instant for the effects of the flow history. The correction is found to be small but may occasionally be significant.

* This work was sponsored by Project SQUID which is jointly supported by the Office of Naval Research, the Office of Scientific Research (Air Force), and the Office of Ordnance Research (Army).
[1] G. Rudinger, J. Appl. Phys. **26**, 981 (1955).

C8. Helmholtz's Instability of Two Superposed Streams. C. M. TCHEN, *National Bureau of Standards.*—Two uniform layers of fluids are superposed. They are incompressible and of different densities, viscosities, and current velocities. Gravity and surface tension are included. The main problem concerned is the role of viscosity whether it changes the instability or it merely modifies the rate of decay and growth. The paper treats the decay and growth, as well as the modes of maximum stability or instability and the modes of neutral stability for various current conditions. The mathematical problem which consists in resolving a characteristic equation of tenth degree necessitates an approximate theory based on approximations accurate simultaneously in three regions of small, medium and large wave numbers. The result can be summarized in the following approximate formula: $n=k^2M[-1\pm(1-\xi/M)^{\frac{1}{2}}]$, in dimensionless form, where $\xi=\epsilon k^{-3}+Rk^{-2}+Tk^{-1}$, n=rate of growth, k=wave number, R=current Reynolds number, T=dimensionless parameter representing surface tension, $M=1-(1-m)\mathrm{erf}k$, m=function of density difference, $\epsilon=+1$ or -1, according whether the upper fluid is lighter or heavier than the lower one. Gravity, viscosity, and density difference are included in the parameters and render them dimensionless. The particular case of vanishing R degenerates the formula into the one valid for the Stokes-Taylor instability.

C9. Electric Sparks and Their Use in Aerodynamic Measurements. HERBERT J. BOMELBURG, *University of Maryland* (introduced by J. R. Weske).—By means of short duration (about 1 μ sec) high voltage (about 20 kv) pulses series of sparks are being generated. The time between two successive sparks can be held constant and the number of sparks is limited to about 10. It was found that the sparks will follow the ionized path of their predecessors if the time interval is smaller than some 10^{-4} sec. The ionized path of preceding sparks is displaced by the flow of air and the displacement is made visible by subsequent sparks. In this way the local velocity of the air can be determined by measuring the spatial displacement and the time interval between two successive sparks. A number of photoslides will be shown which serve to explain the physical phenomena and illustrate various possibilities of application of this new method.

MONDAY MORNING AT 10:00

Boston Room

(G. BREIT presiding)

Theoretical Physics, I

CA1. On the Collective Motion in Nuclei.* STEVEN A. MOSZKOWSKI, *University of California, Los Angeles.*—Recent striking successes in the interpretation of the rotational states in strongly deformed nuclei have stimulated interest in the dynamics of the collective nuclear motion. The nuclear moments of inertia are intermediate between irrotational and rigid values. Now the rotational moment of inertia and more generally the mass parameter B for collective motion can be expressed directly in terms of nuclear energies without requiring detailed knowledge of the wave functions. Thus we have $B=\hbar^2\Sigma_K(\Delta C_K)(E_K-E_L)^{-2}$ where C_K is the reduction in the curvature of the nucleonic energy of the lowest state L due to admixture of state K. The nucleons are assumed to move nearly independently in an ellipsoidal harmonic oscillator potential for which the five $E2$ deformation parameters vary slowly with time. The resulting collective motion can then be approximately separated into (a) a changing distortion of the nuclear wave functions to partially follow the changing deformation of the potential. This flow, in which all the nucleons participate, is irrotational. (b) Strong mixing of close-lying states. This flow, to which only nucleons outside closed shells take part, has strong vorticity and is responsible for the bulk of the mass parameter. Crude estimates indicate that the mass parameter for β and γ vibrations as well as for rotations should be about five times the hydrodynamic value.

* This work was partially supported by the National Science Foundation.

CA2. Configuration Change Excitation and the Four-Group Substructure of Nuclei.* R. W. KING, *Purdue University.*—The excitation of nuclei by change of orbitals exhibits evidence for a quasi α particle or "four-group" nuclear substructure, interpreted as existing within the framework of the strong spin-orbit coupling shell model. This is most clearly illustrated for nuclei with $N-z=3$ in the range $A=37$–43, where configuration change is particularly easy to identify by the associated parity change. Comparison of adjoining isobars shows previous single particle interpretations given to these excited states to be in error, while a multiparticle interpretation based on the four-group model offers an adequate description. The excited states of Cl^{37} and A^{39} provide an especially sensitive test because excitation of the closed shell of 20 neutrons is energetically favored by the four-group model over the proton excitation favored by strict j–j coupling. Present experimental data on the decay of S^{37} and Cl^{39} support the four-group view. This view may be correlated with some appearances of supermultiplet behavior in light nuclei.

* Supported in part by a contract with the U. S. Atomic Energy Commission.

CA3. Experimental Single-Particle Level Spacing near the $1f_{7/2}$ Shell. R. H. NUSSBAUM, *Indiana University.*—Experimental single-particle level spacing is an important basis for theoretical calculations of level structures in nuclides with more than one nucleon (hole) outside closed shells. A survey of experimental data possibly defining the distances between the $1f_{7/2}-1f_{5/2}$, $1f_{7/2}-2p_{3/2}$, $1f_{5/2}-2p_{3/2}$, and $2p_{3/2}-2p_{1/2}$ levels will be presented.

CA4. Realistic Independent Particle Model of the Nucleus.* ALEX E. S. GREEN, *The Florida State University.*—A phenomenological central potential is explored which is characterized by a universal depth V_0, a universal surface extension d, and an inner radius function $a=a_1A^{\frac{1}{3}}+a_0$. The four parameters are adjusted to be in accord with experimenatl information obtained from low energy neutron scattering and from neutron separation energies. The results $V_0=40$ Mev, $d=1$, $a_1=1.32$, and $a_0=-0.8$ (all in 10^{-13} cm), are in reasonable accord with what might be expected from other experimental and theoretical considerations. Since the experimental data used in the adjustment process bound the energy region in which the discreteness of nuclear energies is most evident, one might expect that the eigenvalues and eigenfunctions based upon this phenomenological model would furnish a highly realistic set for the theoretical study of low-energy nuclear transitions within the framework of the IPM of the nucleus. The energy eigenvalues and the important parameters for the energy eigenfunctions are calculated by a procedure siutable for the restricted type of potential under consideration. A simple method is presented for handling small perturbations, particularly the Coulomb perturbation. In the latter case, it is shown that the derived proton eigenvalues agree with experimental proton separation energies, providing one corrects the nuclear potential by approximately one-half of the classical Coulomb potential acting upon an individual proton.

* This investigation was supported by a grant from the U. S. Atomic Energy Commission.

CA5. Mass Surfaces Derived from a Realistic IPM. KIUCK LEE AND A. E. S. GREEN, *The Florida State University.*—A phenomenological diffuse boundary independent particle model adjusted to be in accord with certain neutron scattering and neutron separation energy data is taken as a starting point in the derivation of various nuclear mass surfaces. Analytic expressions are presented for the energy eigenvalue sums. Various corrections to these sums are considered in an effort to obtain a mass surface in accord with the experimental mass surface. Some of these are the inclusion of velocity dependent forces, exchange forces, and repulsive core two-body interactions. The implications of the various results are discussed.

CA6. Two-Body Spin-Orbit Forces in the Shell Model.* W. M. VISSCHER AND R. A. FERRELL, *University of Maryland.*—A two-nucleon spin-orbit force of the form $(-\alpha/\hbar)(1-m+mp)(\mathbf{s}_1+\mathbf{s}_2)\cdot[\mathbf{r}_{12}x(\mathbf{p}_1-\mathbf{p}_2)]\exp-\beta r_{12}^2$, with $\alpha=-27$ Mev, $m=0.72$, and $\beta^{-\frac{1}{2}}=1.73\times10^{-13}$ cm, fits the $\alpha-p$ scattering data, the $p_{\frac{1}{2}}-p_{\frac{3}{2}}$ splitting in N^{15}, and the low-lying levels of the N^{14} spectrum.[1] When the interaction of a single d-particle outside the closed p-shell is calculated on the basis of these parameters, it is found that the $d_{\frac{1}{2}}-d_{\frac{3}{2}}$ splitting is 11 Mev, or, written as a one-body force, the effective interaction is $-4.5\mathbf{l}\cdot\mathbf{s}$ Mev. A reinterpretation of the low-lying $\frac{3}{2}^+$ levels in O^{17} (5.08, 7.37 Mev), one of which has been supposed to be $d_{\frac{3}{2}}$,[2] would be required if this result is valid. We propose the following interpretation. The O^{16} spectrum contains two positive parity levels, 0^+ at 6.06 Mev, 2^+ at 6.91 Mev, usually assumed to be collective excitations. An $s_{\frac{1}{2}}$ particle coupled to the O^{16} 2^+ state could give one of the $\frac{3}{2}^+$ levels in O^{17}, a $d_{\frac{3}{2}}$ particle the other. Calculations of coupling energies will be presented.

* Supported by the Office of Naval Research.

[1] W. M. Visscher and R. A. Ferrell, Phys. Rev. (to be published).

[2] J. P. Elliott and B. H. Flowers, Proc. Roy. Soc. (London) **229**, 536 (1955).

CA7. Dependence of the C^{14} Beta Decay on the Shapes and Ranges of the Nuclear Forces.* D. T. GOLDMAN, W. M. VISSCHER, AND R. A. FERRELL, *University of Maryland.*—In the framework of the shell model without configuration mixing Talmi and Jancovici[1] have observed that the two terms in the C^{14} β-decay matrix element can cancel and yield the observed long half-life only if the tensor force is taken into account. Visscher and Ferrell,[2] using oscillator wave functions and assuming Gaussian interactions, determine the tensor force strength by requiring cancellation. For comparison with the independent determination of the tensor force from the deuteron ground state,[3] we have investigated the cancellation for a variety of interaction shapes and ranges. For Yukawa shape, parameters which account for both the deuteron data and the C^{14} lifetime are: central range $=1.18\times10^{-13}$ cm, tensor range $=1.54\times10^{-13}$ cm, ratio of tensor to central strength $=0.9$. The position of the N^{14} first-excited state further determines the tensor force by fixing its exchange character.

* Research supported by the Office of Naval Research and the National Science Foundation.
[1] B. Jancovici and I. Talmi, Phys. Rev. **95**, 289 (1954).
[2] W. M. Visscher and R. A. Ferrell, Phys. Rev. **99**, 649 (A) (1955); Phys. Rev. (to be published).
[3] W. Rarita and J. Schwinger, Phys. Rev. **59**, 436 (1941); H. Feshbach and J. Schwinger **84**, 194 (1951).

CA8. Radii of the p-Shell Nuclei.* R. A. FERRELL AND W. M. VISSCHER, *University of Maryland.*—Utilizing experimental Coulomb energy differences between isobaric states, and oscillator wave functions, one can determine the radii of the nuclei of masses five to fifteen.[1] The determination can be carried out without specific assumption of a coupling scheme except for masses eight to twelve, which can be calculated assuming $j-j$ coupling.[1] The effect of deviations from $j-j$ coupling can be estimated. Both the C^{12} shape and size agree well with electron scattering results.[2] We find that all the p-shell nuclei have a root-mean-square radius of $(2.3\pm0.2)\times10^{-13}$ cm except masses five and six. These have the anomalously large value of 2.8×10^{-13} cm, corresponding to weak binding. Nuclear radii can be independently calculated by minimizing the total nuclear energy with respect to variations in the size parameter of the oscillator wave functions. Resulting values for energy as well as radius will be presented for a few cases. Calculations for mass six using other than oscillator wave functions will also be discussed.

* Research supported by the Office of Naval Research and by the National Science Foundation.
[1] B. C. Carlson and I. Talmi, Phys. Rev. **96**, 436 (1954).
[2] Jerome H. Fregeau and Robert Hofstadter, Phys. Rev. **99**, 1503 (1955).

CA9. Neutron Shell Structure in a Diffuse Potential Well.* R. D. LAWSON, A. A. ROSS, AND HANS MARK, *University of California, Berkeley.*—The bound states of the potential $V(r)=-V_0/[1+\exp\alpha(r-a)]$ have been studied using a differential analyzer. We have found that good shell structure (including the shell at $N=126$) and level ordering may be obtained by choosing $V_0=42.8$ Mev, $\alpha=1.45\times10^{13}$ cm^{-1}, $r_0=1.3\times10^{-13}$ cm ($a=r_0A^{\frac{1}{3}}$) and a spin-orbit coupling parameter $\lambda=39.5$ times the Thomas term. For example, with these parameters we find that the top neutron in the 82 shell should be in a $2d_{3/2}$ state. The next level to be bound is the $2f_{7/2}$ state. Both these results, which are difficult to obtain with a square well, are in agreement with experiment. For heavy nuclei, the last neutron is bound by approximately the correct amount. However, in lighter nuclei the binding energy, although ~8 Mev, is too little. One must, therefore, increase the well depth for lighter nuclei. With these parameters the zero-energy S-wave resonances in the neutron-scattering cross section occur at $A=56$ and 166 in reasonable agreement with experiment.

* Supported in part by the Office of Ordnance Research, U. S. Army.

CA10. Proton Shell Structure in a Diffuse Potential Well.* A. A. ROSS, HANS MARK, AND R. D. LAWSON, *University of California, Berkeley.*—The bound states for protons were investigated for various A using the same α, λ, and r_0,[1] assuming a uniform charge distribution out to $r_0A^{\frac{1}{3}}$. Since the V_0 for the neutrons will not bind the correct number of protons it was adjusted in each case to give approximately the right binding energy for the last proton. The necessary depth decreased with decreasing A. A good shell structure was found and in addition the level sequence differed from that of the neutrons in a manner corresponding to that deduced from ground state spins and parities. For example, the last level in the 82 shell was now found to be $S_{\frac{1}{2}}$ and the first level in the next shell was $1h_{9/2}$. Since both here and experimentally the protons lie inside the neutrons, a more consistent nuclear potential might be $V(r)=-V_1/(1+\exp\alpha(r-r_1)]-V_2/[1+\exp\alpha(r-r_2)]$, where the subscripts 1 and 2 refer to neutron and proton density effects respectively.

* Supported in part by the Office of Ordnance Research, U. S. Army.
[1] Lawson, Ross, and Mark (preceding abstract).

CA11. Energy Levels in a Velocity-Dependent Potential.* HANS MARK, R. D. LAWSON, AND A. A. ROSS, *University of California, Berkeley.*—Using the Hamiltonian proposed by Johnson and Teller[1] the bound states of the single-particle wave equation,

$$\left[-\frac{\hbar^2}{2m}\nabla(1-kV)\nabla+V\right]\psi=E\psi,$$

have been investigated with $K=1/V_0$. For comparison, the same α, r_0, and λ as in abstract CA9 have been used. The depth of the potential necessary to bind the last neutron at $A=140$ with the proper energy is 69 Mev. The proper level sequence may be obtained by choosing α slightly smaller than in the velocity independent case. The square well is a bad limiting case since the high angular momentum states are bound too tightly. For a square well, the additional term $-(\hbar^2K/2m)\nabla V\nabla\psi$ acts as a purely attractive delta-function potential. For a diffuse well this term becomes partially repulsive since $\nabla\psi$ changes sign near the nuclear radius.

* Supported in part by the Office of Ordnance Research, U. S. Army.
[1] M. H. Johnson and E. Teller, Phys. Rev. **98**, 983 (1955).

CA12. Nuclear Saturation with Monotonic Potentials.* M. M. DUNCAN,† *Duke University.*—The Brueckner[1] self-consistent method for a "coherent" model was used to evaluate binding and symmetry energies under the assumption of monotonic type nuclear two-body interactions. Square-well potentials with varying Majorana and Wigner exchange mixtures, but no tensor forces were used. The range and depth of the singlet interaction were chosen to give the correct low-energy scattering. Triplet wells of three different ranges each with two different depths were tried. The larger depth was adjusted to bind the deuteron, while a smaller depth was introduced to represent the averaging out of the tensor forces. The exchange mixture was varied between full and 0.8 Majorana contribution. The correct binding energy at the correct nuclear density could be achieved within this range of parameters but the symmetry energy will then be too large.

* Work supported in part by the National Science Foundation.
† Shell Fellow 1954–1955.
[1] Brueckner, Levinson, and Mahmoud, Phys. Rev. **95**, 217, (1954); K.A. Brueckner, Phys. Rev. **96**, 508 (1955); **97**, 1353 (1955).

MONDAY AFTERNOON AT 2:00

Manhattan Center, Gold Room

(F. N. FRENKIEL presiding)

Fluid Dynamics, II

D1. Turbulent Heat Transfer in a Boundary Layer with Discontinuous Wall Temperature.* S. CORRSIN AND D. S. JOHNSON,† *The Johns Hopkins University.*—Measurements have been made of the concomitant velocity and thermal fields in the turbulent boundary layer passing over a small stepwise discontinuity in wall temperature. The instantaneous surface of demarcation between heated and unheated fluid was found to be relatively sharp and distinct at all downstream positions, resulting in intermittent temperature fluctuation signals well within the fully turbulent region of the momentum boundary layer. Sufficient data were taken at one station to permit estimation of the turbulent energy balance and of all terms in the corresponding thermal fluctuation equation.[1]

* Supported by the Office of Scientific Research, Air Research and Development Command.
† Now at the Bell System Laboratories.
[1] S. Corrsin, J. Appl. Phys. **23**, 113 (1952).

D2. On the Theory of Homogeneous Turbulence in Compressible Fluid. M. Z. v. KRZYWOBLOCKI, *University of Illinois* (introduced by R. D. Hill).—Kampé de Fériet provided the proof of the existence of the second-order tensor in the theory of homogeneous turbulence in an incompressible fluid. The author furnishes a proof of the existence of this tensor in the theory of homogeneous turbulence of a compressible fluid. The proof involves a relation between the unitary transformation in the Hilbert space and the transformations on the stationary random functions.

D3. On the Structure of a Hydromagnetic Shock Wave. M. H. ROSE AND H. GRAD, *N. Y. U.*—The steady-state profile of a one-dimensional shock with a perpendicular applied magnetic field is discussed. The basic equations are those of conservation of mass, momentum and energy together with Maxwell's equations. The gas is assumed perfect; viscosity and heat conductivity are neglected. The state of the shock is found to depend on two parameters instead of on one as in the case of a pure hydrodynamic shock.* It is also shown that even a vanishingly small magnetic field outside the shock will be amplified inside and may attain values that are roughly ten times those of the pressure. Estimates are made of the shock thickness which is shown to be of the order of the Larmor radius. The latter, therefore, has the role of the mean free path in ordinary gas dynamics.

* One of these is related to the ordinary parameter of gas dynamics in the absence of a field; the other depends on the amount of magnetic field present.

D4. Vibrational Relaxation in Oxygen and Nitrogen.* VERNON H. BLACKMAN, *Princeton University* (introduced by W. Bleakney).—Shock waves of speeds $M_1 = 3$–7.5 in oxygen and $M_1 = 5$–10 in nitrogen have been studied with an interferometer and relaxation times, τ, for the approach to vibrational equilibrium behind the shock were measured. τ (atmospheric) varies from 54 μsec at 800°K to 1.3 μsec at 3000°K for oxygen and from 19 μsec at 3500°K to 5 μsec at 5500°K for nitrogen. $\mathrm{Ln}\tau$ for oxygen, plotted against T^{-1}, is not quite the straight line predicted by the Landau-Teller theory. The density ratios across the shock were measured and compared to values calculated by the Bethe-Teller method for variable specific heats. Agreement between the measured and calculated values is satisfactory. Experiments were also performed on oxygen-nitrogen mixtures to determine the effect of nitrogen on the approach to equilibrium of the oxygen. It was found that O_2-N_2 collisions at $\sim$2000°K are 40% as effective in transferring energy to the oxygen as O_2-O_2 collisions. A shock detecting device with a signal rise time <1 μsec, consisting of an evaporated gold film which changes its resistance when heated by the shock, was also developed.

* Supported by the Office of Naval Research.

D5. Interaction of Shock Waves with a Thermal Layer. ROBERT VARWIG AND JAY ZEMEL, *U. S. Naval Ordnance Laboratory.*—A series of experiments has been conducted to determine the nature of the interaction resulting when a shock wave passes through a heated air layer and is reflected from a rigid boundary. Investigations were made with cylindrical shock waves produced in the shock tube, and spherical shock waves produced by a spark discharge. Layers of air displaying moderate-to-strong thermal gradients were produced by heated metal plates, which also served to reflect the incident shock. Severe distortion of the shock was observed as it propagated through the thermal layer. When the shock was reflected from the heated plate, a Mach stem developed earlier and grew more rapidly than when a similar shock was reflected from an unheated plate. When the cool-warm air interface was well-defined, a "retransmitted" wave appeared following the apparent breakaway of the thermally distorted shock from the undistorted shock in the cool-air region. For poorly defined interfaces no such development occurred. A description of the development of the interaction is given, illustrated by shadowgraphs depicting the sequence of events. A comparison is made with the work of others in which shocks were propagated across an interface between two homogeneous media of different sonic speeds.

D6. Shock Wave Diffraction Studies in a Water Table: Comparison with Shock-Tube Results. DONALD R. F. HARLEMAN, *M.I.T.*—A study was made of the feasibility of using a water table and surge generator as a shock-tube simulator for the investigation of transient shock wave diffraction as applied to the shock loading of structures. The theoretical basis for a modified hydraulic analogy was established and the capabilities and limitations of the water table as a low-cost experimental facility were investigated. The method of conversion of water table observations directly into results for air overcomes the limitation, of the classical hydraulic analogy, to the "analog gas" having a ratio of specific heats equaling two. Experimental equipment and procedures for water-table studies are outlined. An electronic depth probe for the measurement of transient water depths is described and techniques for obtaining shadowgraphs of the diffraction patterns are presented. The experimental results of the water-table studies are presented in the form of direct comparisons with shock-tube results for various geometrically similar models at the same incident shock strengths. For simple geometrical models without multireflections, the water-table pressure distributions are quantitatively reliable, within approximately 10%, when compared with shock tube results. For complex models the agreement is of the order of 15 to 20%.

D7. Onset of Mach Reflection for Two Strong Unequal Shocks.* W. R. SMITH, *Princeton University.*—In previous studies of shock-wave interactions involving two waves of

equal strengths.[1] the conditions for sonic flow behind the reflected waves were reached before Mach reflection began. Recently performed experiments involving the interaction of two straight, strong shocks of different strengths show that this is not always the case. Two wedges, one solid the other slotted, were used to produce the interacting shocks in a shock tube by reflection of a plane incident shock wave. A series of unequal interacting shock waves was studied by the use of a Mach-Zehnder interferometer. In these the onset of Mach reflection also occurred only after sonic flow was reached behind the reflected shocks. However, for the case of the two strongest interacting shocks studied, where the incident shock density ratios were $\eta=1.95$ and $\eta'=2.67$ in air, Mach reflection was found to begin at an angle $\theta=79.1°\pm0.2°$. At this angle the flows behind the reflected waves are still supersonic.

* Supported by the Office of Naval Research.
[1] W. Bleakney and A. H. Taub, Revs. Modern Phys. 21, 584 (1949).

D8. Some Aspects of Unsteady Laminar Boundary Layer Flows. SIN-I CHENG (introduced by W. Bleakney).—The viscous flow over a semi-infinite flat plate started to move with velocity $u=0$ for $t\leq 0$ and $u=t^n$ for $t>0$ is analyzed in detail with the boundary layer equations. Particular emphasis is put on joining the solution at downstream infinity to the solution in the upstream region. The method of trying to perturb the downstream x-independent Rayleigh type solution, including the possibility of singular perturbations, fails to introduce any nonvanishing x-dependent perturbations, which is interpreted physically that such a process is invalid. A series solution is then constructed from the leading edge under the boundary-layer assumption that vorticity does not diffuse in the longitudinal direction. Numerical results show that the skin friction approaches the value given by the Rayleigh type solution to within 2% when the distance from the leading edge is about 4/10 of the distance traveled by the plate. Continuation of the solution into the downstream region for the flow field near the plate can be effected by regular perturbations. Such a continuation eventually approaches the Rayleigh-type solution in the far downstream region. Hence, the solution so determined possesses the proper limiting behaviors at both small x and large x. The limiting behaviors of the solution at small t and large t are also found to be proper.

D9. On the Laminar Boundary Layer Generated by a Traveling Shock.* DANIEL BERSHADER AND JOHN ALLPORT, *Princeton University.*—The viscous layer developed behind a shock wave of constant strength moving along a flat surface is equivalent to a generalized, steady boundary layer with relative motion between surface and leading edge. Solutions of the equations for the simple case of viscosity proportional to temperature and a Prandtl number of unity are in good agreement with results of others obtained by somewhat different methods. The skin friction, heat transfer, and nondimensional profiles of velocity and temperature lose universality because of the additional parametric dependence. Interferometric studies show moderate agreement with theory, with occasional disparities up to 15%. To obtain an independent check of the predicted friction constants, measurements of the surface temperature jump following passage of the shock wave were made with a thin-film resistance thermometer. Agreement with theory exists within the experimental uncertainty of a small fraction of a degree in temperature rise. The thin-film results are confirmed by recent measurements of Emrich and Chabai, reported elsewhere in this session, who include a discussion of the basis for the method.

* Research supported by the Office of Naval Research.

D10. Measured Wall Temperature Jump on Shock Passage.* RAYMOND J. EMRICH AND ALBERT J. CHABAI, *Lehigh University.*—As described in the preceding paper by Bershader and Allport, the predicted heat flux through a laminar boundary layer to the shock tube wall starts abruptly on shock passage and varies inversely with the square root of the time thereafter. Heat flux with this time dependence into a semi-infinite medium produces a temperature jump at the surface at zero time and a constant temperature thereafter. Such a temperature-time variation has been observed at Princeton and at Lehigh, using evaporated film resistance thermometers on the shock tube wall.[1] After an interval of constant temperature, a further marked increase is observed which is interpreted as breakdown of laminar flow. Recent measurements have been made with thermometers of rhodium evaporated on glass[2] which maintain exceptionally constant resistance with time, current, and rough usage. Theoretically predicted values of temperature jump agree well with measured values over a range of shock strength and initial gas conditions.

* Supported by the U. S. Office of Naval Research.
[1] Chabai and Emrich, J. Appl. Phys. 26, 779 (1955).
[2] We are indebted to E. J. Serfass for these rhodium thermometers.

Business Session of the Division of Fluid Dynamics

(To be placed at the Chairman's choice)

MONDAY AFTERNOON AT 2:00

Grand Ballroom

(R. A. PECK, JR., presiding)

Reactions of Transmutation and Nuclear Energy Levels, He through C

DA1. Scattering of 40-Mev Protons from He^4.* R. M. EISBERG, *University of Minnesota.*—The existence of an excited state in He^4 may be investigated by bombarding these nuclei with a monoenergetic beam of protons and looking for a group of inelastically scattered protons corresponding to excitation of the state. Using this technique at a bombarding energy of 32 Mev, Benveniste and Cork[1] found no evidence of a state in He^4 of exciataion energy less than 23 Mev. The 40 Mev beam of the Minnesota proton linear accelerator is being used to extend the search for a state in He^4 to higher excitation energies. A gas target is bombarded and particles emitted at forward angles are detected in a scintillation counter which measures their energy. By observing the energy loss in traversing thin foils, the masses of the particles are also measured. Elastically scattered protons and recoil He^4 are seen, as well as deuterons and recoil He^3 from the ground-state (p,d) reaction. A continuum of protons from $(p,2p)$ and (p,pn) reactions is observed. Preliminary data show no evidence for a distinct group of inelastically scattered protons corresponding to a state in He^4 of excitation energy less than 28 Mev.

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] J. Benveniste and B. Cork, Phys. Rev. 89, 422 (1953).

DA2. Elastic and Inelastic Scattering of 31-Mev Alpha Particles from Light Nuclei.* H. J. WATTERS, *M.I.T.*—Thin Li^6, C^{12}, and Mg^{24} targets have been bombarded with alpha particles of energy 31.5±0.4 Mev. Angular distributions of elastic and inelastically scattered alpha particles have been measured using a particle selective technique[1] which involves the coincidence measurement of E and dE/dx. The elastic angular distributions show well-defined maxima and minima and are compared to optical diffraction by an opaque disk. Inelastic angular distributions have been obtained for two excitation levels in each of the three target nuclei. They also exhibit strong maxima and minima and are insensitive to small changes in beam energy. There appears to be a negligible contribution to the cross section at angles greater than 90° center of mass. A basic "surface" or "direct" interaction theory, similar to that of Austern, Butler, and McManus, has been developed[2] and the experimental data will be compared with the predicted angular distributions.

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] F. A. Aschenbrenner, Ph.D. thesis, Massachusetts Institute of Technology, June, 1954.
[2] L. S. Rodberg, Massachusetts Institute of Technology.

DA3. Excitation Curves for the $Be^9(\alpha,n)C^{12}$, $C^{13}(\alpha,n)O^{16}$, and $Be^9(\alpha,n\gamma)C^{12}$ Reactions.* J. P. SCHIFFER, T. W. BONNER, ALFRED A. KRAUS, JR., AND J. B. MARION, *Rice Institute.*—The above reactions were studied from 1.6 to 5.2 Mev bombarding energies at 0° and 90°. For Be^9 the neutron yield shows resonances at 1.9, 2.3, 2.6, 3.98, and 4.3 Mev. Above 4.3 Mev there are one or more broad resonances. Except for a 60-kev resonance at 3.98 Mev, all resonances have $\Gamma \geq 200$ kev. All but the 2.3-Mev resonance show up on the 4.4-Mev gamma yield. Resonance cross sections for neutrons range from 10 to 75 mb/sterad, and for gammas from 4 to 16 mb/sterad, both being generally more intense at 0°than at 90°. The $C^{13}(\alpha,n)O^{16}$ reaction shows resonances at 2.09 Mev ($\Gamma=120$ kev), 2.25 (80), 2.43 (80), 2.61 (≤ 20), 2.69 (≤ 20), 2.775 (≤ 20), 2.825 (≤ 20), 3.09 (90), 3.33 (140), 3.42 (30), 3.67 (≤ 20), 3.730 (≤ 20), 4.125 (≤ 20), 4.42 (30), 4.50) (70), 4.63 (≤ 20), 4.74 (170), 4.85 (100), 5.05 (65). These resonances have cross sections from 1 to about 30 mb/sterad and with two exceptions are more intense at 0°.

* Partially supported by the U. S. Atomic Energy Commission.

DA4. Angular Distributions and Excitation Curves for Resolved Neutron Groups from the $Be(\alpha,n)$ Reaction.* J. R. RISSER, C. M. CLASS, AND J. E. PRICE, *Rice Institute.*—The neutron yields from the reaction $Be^9(\alpha,n)C^{12}$ ($Q=5.7$ Mev) and $Be^9(\alpha,n)C^{12*}$ ($Q=1.3$ Mev) have been investigated in the range of bombarding energies from 2 to 4.5 Mev. Excitation curves for the neutrons of each group were taken at 0°, and the angular distributions were measured at a number of energies. The detector was of the proton-recoil-counter type, consisting of a thin polyethylene radiator and scintillation crystal with a gas proportional counter in coincidence between the radiator and crystal. The ground state neutrons show a resonance at 2.6 Mev and broad resonance structure in the 4 to 4.5 Mev region. The first-excited-state group shows a weak resonance at 2.6 Mev, a narrow intense resonance at 4 Mev and broad resonance structure above 4 Mev. At the higher energies the angular distributions exhibit forward and probably also backward peaking such that states of the compound nucleus with J at least 5/2 are probably required.

* Supported in part by the U. S. Atomic Energy Commission.

DA5. Angular Distributions of 44-Mev Alpha Particles Scattered Elastically and Inelastically from Beryllium.* G. W. FARWELL AND D. D. KERLEE, *University of Washington.*—Spectra of alpha particles scattered from beryllium at angles from 28° to 114° (CM) have been studied. Relative intensities of alpha groups corresponding to elastic scattering and inelastic scattering with excitation to the 2.43-Mev level in Be^9 were measured. Absolute cross sections were estimated by comparison with Pb Coulomb scattering. Account was taken of the prominent continuum of alphas representing such reactions as $Be^9(\alpha,\alpha'n)Be^8 \rightarrow 2\alpha$; this continuum becomes unappreciable at about $Q=-2$ Mev. Near 85° the inelastic cross section ($Q=-(2.4\pm0.1)$ Mev as measured here) exceeds the elastic; the magnitude of the former at large angles suggests a collective mode of excitation and rules out single-particle excitation because of the large momentum transfer involved.[1] There is indication of an inelastic group at $Q=-3.1$ Mev at backward angles, but the evidence is not clear. Between 28° and 71°, significant contributions from $Q=-1.8$ and -3.1 Mev groups are excluded.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] J. S. Blair and E. M. Henley (abstract DA6, this bulletin).

DA6. Theoretical Angular Distributions for Scattering from Beryllium.* J. S. BLAIR AND E. M. HENLEY, *University of Washington.*—Angular distributions of moderate energy alphas and protons or high-energy electrons scattered elastically, or inelastically with excitation of low-lying levels in Be^9, are calculated in the impulse approximation. For moderate momentum transfers (of order $2\hbar$ fermi^{-1}), and therefore intermediate angles, only collective rotational and vibrational states can be excited, with angular distributions characteristic of the angular momenta and modes of oscillation. Single particle excitation can occur for small momentum transfer by direct collision with the neutron, or for rather large momentum transfer by indirectly "shaking" the neutron in a collision with the collective nucleons. A specific collective model is adopted for Be^9—namely, a semirigid dumbbell of two alpha particles to which a single neutron is strongly coupled. The distance between the centers of the alpha particles and the stiffness of the dumbbell can be estimated empirically from the resonances in $\alpha-\alpha$ scattering and the location of strongly excited levels in Be^9. Calculations with this model are compared to experimental distributions for alpha[1] and proton[2] scattering.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] G. W. Farwell and D. D. Kerlee (abstract DA5, this bulletin).
[2] R. G. Finke, U.C.R.L. 2789, November, 1954 (unpublished).

DA7. Excitation Functions and Angular Distributions of $B^{10}(p\alpha)Be^7$.* JAMES W. CRONIN,† *University of Chicago.*—Measurements on the excitation function and angular distribution of $B^{10}(p\alpha)Be^7$ have been carried out with apparatus which employs electrostatic energy analysis. Transitions to the ground and first excited states of Be^7 were observed. Excitation functions have been measured for proton energies from 0.8 to 1.65 Mev for laboratory angles of 90° and 145°. Angular distributions have been measured at 1.0, 1.2, 1.36, 1.5, and 1.63 Mev, and at 1.3, 1.5, and 1.63 Mev for the excited state. The excitation functions show resonances at 1.17 and 1.5 Mev for the ground state, and 1.55 Mev for the excited state transition. The resonances are superposed on a uniform isotropic background. The 1.17-Mev resonance shows nearly an isotropic distribution for transitions to the ground state. At the 1.5-Mev resonance the angular distribution is $1-0.53\cos^2\theta$ with very small interference terms. The angular distributions leading to the excited state show a small asymmetry with the backward angles being favored. The absolute cross section at 90° in the laboratory at 1.5 Mev proton energy is 21±4 mb/sterad. This value is in agreement with previous work. The angular distributions show that the two resonances have opposite parity and suggest assignments of $3/2^-$ and $7/2^+$ for the 1.17- and 1.50-Mev resonances, respectively.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at Brookhaven National Laboratory.

DA8. X-Ray Excitation of 15-Mev Level in C^{13}.* E. G. FULLER, E. HAYWARD, AND N. SVANTESSON, *National Bureau of Standards.*—A pronounced maximum in the spectrum of photons scattered by a carbon target irradiated by bremsstrahlung spectra having 15 Mev $< E_{max} \leq 40$ Mev has been observed. The experimental arrangement was that used in the elastic scattering measurements.[1] The threshold for the production of this line based on the Cu^{63}, Cu^{65}, B^{10}, and $Be^{9}(\gamma,n)$ thresholds is 15.0 ± 0.2 Mev. The line presumably results from the elastic scattering by the 15.09 Mev, $T=1$ level in C^{13}.[2] The excitation function of this line as a function of E_{max} is consistent with a 15.09-Mev isochromat calculated from Schiff bremsstrahlung spectra. 2.1 g/cm² of graphite placed between the scattering target and the betatron attenuated the scattered counts by a factor of 0.49 ± 0.04. 7.8 g/cm² of graphite placed between the scattering target and the detector reduced the scattering intensity by 0.81 ± 0.07. For this latter case the expected electronic transmission is 0.87. The level width is then less than the energy given the recoiling C nucleus ($\sim 10^6$ ev). As defined in (1) the mean scattering cross sections from 14.4 to 15.8 Mev is 0.7 ± 0.2 mb.

* This research was supported by the United States Air Force, through the Office of Scientific Research of the Air Research and Development Command.

[1] E. G. Fuller and E. Hayward, Phys. Rev. (to be published).
[2] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **27**, 77 (1955).

DA9. Angular Distributions of Protons from the $C^{12}(He^3,p)N^{14}$ Reaction. RICHARD JOHNSTON AND H. D. HOLMGREN, *Naval Research Laboratory.*—The angular distributions of protons from the $C^{12}(He^3,p)N^{14}$ reaction leaving N^{14} in the ground state, first excited state and second excited state have been measured for a bombarding energy of 2 Mev. The protons were observed in 200 micron C2 emulsions placed at 10-degree intervals from 10 to 90 degrees and 95 to 155 degrees. The three proton groups were identified by measuring the range spectrum of proton tracks in each emulsion. The angular distributions exhibit a lack of symmetry about 90 degrees with the ground-state protons p_0 having a maximum intensity near 70 degrees, p_1 a maximum in the region of 95 degrees, and p_2 having a minimum at about 55 degrees and a maximum close to 140 degrees.

DA10. Inelastic Scattering of 40-Mev Alpha Particles from Carbon.* H. E. WEGNER AND G. IGO, *Brookhaven National Laboratory.*—Thin carbon targets have been bombarded with alpha particles. The angular distribution of inelastically scattered alpha particles corresponding to the 4.4-Mev excited states of C^{13} has been measured and found to be asymmetric about 90°. The differential cross section decreases as a function of increasing angle to a minimum at 23° in the laboratory system followed by a rise to a maximum at 29°. The cross section beyond 29° decreases monotonically. At 22 Mev, bombarding energy, the distribution is also asymmetric as recently reported.[1] Other low-lying levels in carbon are being investigated by the authors.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] Rasmussen, Miller, and Sampson, Phys. Rev. **100**, 181 (1955).

DA11. Angular Distributions of the $C^{13}(He^3,\alpha)C^{12}$ Reaction. H. D. HOLMGREN, *Naval Research Laboratory.*—The angular distributions of the ground state and first excited state α-particle groups from the $C^{13}(He^3,\alpha)C^{12}$ reaction have been investigated in the angular region extending from 5° to 150° at a bombarding energy of 2 Mev. The He^3 particles were accelerated with the NRL 2-Mev Van de Graaff generator and the angular distributions were measured with a multiplate reaction camera having 50-micron E1 nuclear emulsions placed at 5° intervals. Each angular distribution exhibits a strong forward maximum and a sharp minimum in the region of 55°. The yield of the ground-state group increases slowly with increasing angle at large angles. The first excited state group appears to have a maximum near 130° and is about 4 times as intense as the ground-state group over most of the angular region.

DA12. Photo- and Electrodisintegration of C^{13}. GERARD DE SAUSSURE AND EUGENE GUTH, *ORNL.*—In measurements on sugarwater (Trubey and Blizard, ORNL) neutrons showed up attributable only to the $C^{13}(\gamma,n)C^{12}$ reaction. These measurements yield a very rough value of σ_{photo}. For the $Be^9(\gamma,n)Be^8$ reaction, a simple single particle mode[1] was successful in describing the existing and predicting new.[2] The theory is based on general principles, e.g. selection rules and can easily be reconciled with shell theory[3] and/or the α-particle model. The same model was applied to C^{13}—*mutatis mutandis*. The similarity of the level schemes at low energies of Be^9 and Be^8 is an argument for the validity of the single particle model. The levels at 1.7 and 4.8 Mev of Be^9 correspond to the ground state and the level at 2.9 Mev respectively of Be^8. Moreover, the width of the 4.8 level of Be^9 is about the same as that of the 2.9 level of Be^8. The relation of the level schemes of C^{13} and C^{12} is similar to that of Be^9 and Be^8 though less clear-cut. While the dissociation energy of C^{13} is about three times that of Be^9, the magnetic moment of C^{13} is much closer to the Schmidt line than that of Be^9. The last item favors a single particle model.

[1] E. Guth, Phys. Rev. **55**, 411 (1939); Guth and Mullin, Phys. Rev. **76**, 234 (1949).
[2] Verified, e.g., by Moak, Good, and Kunz, Phys. Rev. **96**, 1663 (1954); Almquist, *et al.*, Phys. Rev. **99**, 631(A) (1955); Lee and Inglis, Phys. Rev. **99**, 96 (1955); Gossett, *et al.*, Phys. Rev. **100**, 203 (1955).
[3] See Lane and Wilkinson, Phys. Rev. **97**, 1199 (1955).

DA13. Production and Properties of C^{15}. R. A. DOUGLAS, B. GASTEN, J. DOWNEY, AND AMBUJ MUKERJI,* *University of Wisconsin.*†—The yield of C^{15} from $C^{14}(d,p)C^{15}$ has been studied from $E_d = 1.3$ to 3.0 Mev by observing the C^{15} radioactivity with a 2 in.×2 in. NaI(Tl) scintillator. Below $E_d = 1.3$ Mev only a weak 7.4-sec activity could be detected, presumably N^{16} from radiative capture of deuterons by C^{14}. This result is consistent with our $Q = -1.0$ Mev.[1] Subtraction of this period from the observed activity for $E_d > 1.3$ Mev gives 2.25 ± 0.05 sec for the half-life of C^{15}. The yield curve shows broad resonances ($\Gamma > 100$ kev) at $E_d = 2.05$ and 2.73 Mev. A plastic scintillator (2 in.×2 in.) was used to examine the beta spectrum. The resulting Kurie plot indicates a complex beta spectrum with a weak component to the ground state. The gamma spectrum ($E > 1$ Mev) as measured by the 2 in.×2 in. NaI(Tl) scintillator shows only a single intense 5.3-Mev transition. Possible spin assignments for C^{15} will be discussed.

* On study leave from Tata Institute of Fundamental Research, Bombay, India.
† Work supported in part by the Wisconsin Alumni Research Foundation and the U. S. Atomic Energy Commission.
[1] Douglas, Broer, and Chiba, Bull. Am. Phys. Soc. **30**, No. 7, 26 (1955).

MONDAY AFTERNOON AT 2:00

Empire Room

(A. G. SHENSTONE presiding)

Optical Physics

E1. Broadening of Hydrogen Lines by Ions and Electrons. ALAN C. KOLB, *Naval Research Laboratory and University of Michigan.*—The broadening of hydrogen lines in a high-temperature, partially-ionized gas is discussed in the classical path approximation. Both ion and electron interactions are taken into account without the usual assumption of binary electron collisions with the radiating atom. Nonadiabatic as well as adiabatic effects are considered and shown to be comparable in their contribution to the electron broadening. It is also shown that in many applications electron broadening cannot be neglected in comparison to the usual Holtsmark ion broadening. The theoretical results will be compared with other classical path theories and with a recent quantum-mechanical treatment.[1] A discussion of the present theory in connection with recent shock tube data will be given.[2] The theory will also be illustrated by a detailed application to Layman α where it is shown that the quantum-mechanical[1] and classical path theories for electron broadening are equivalent after making certain minor additions to the former.

[1] Kivel, Bloom, and Margenau, Phys. Rev. **98**, 495 (1955).
[2] E. B. Turner, unpublished data, University of Michigan.

E2. Correlation of Tabulated Values of the Light-Scattering Functions of Spherical Particles. DONALD A. MELNICK AND J. K. BRAGG, *Operations Research, Inc.**—The existing[1-3] tabulated values of the reduced cross section, $K(=\sigma/\pi a^2)$, of nonabsorbing spherical dielectric particles have been correlated by plotting K *vs* $\alpha(n-1)$, where α is $2\pi a/\lambda$ and n is the index of refraction. This parameter can be calculated by the Mie formula, in which it is given as function of α and n. Many values of K have been tabulated,[1-3] but since its behavior was not understood, it has so far been impossible to interpolate between tabulated values in either the α or the n direction. Van de Hulst[4] first touched on the physical significance and the apparent success of plotting K *vs* $\alpha(n-1)$. The authors have shown that the tabulated values can thus be simply correlated. When plotted against this variable, there is little variation in the n direction and therefore interpolation is simple and accurate. Oscillations of diminishing amplitude of period π in the variable $\alpha(n-1)$ are definitely shown to occur. The few known values of $\bar{\mu}$, the average cosine of the angle of deviation of the light, can be correlated in an analogous fashion.

* This work performed under subcontract with the Operations Research Office of The John Hopkins University.
[1] A. N. Lowan, *Tables of Scattering Functions for Spherical Particles.* Applied Math. Series No. 4 (U. S. National Bureau of Standards, 1948).
[2] R. O. Gumprecht and C. M. Sliepcevich, *Light Scattering Functions for Spherical Particles* (University of Michigan, Eng. Research Inst., 1951).
[3] H. G. Houston and W. R. Chalker, J. Opt. Soc. Am. **39**, 955 (1949).
[4] H. C. van de Hulst, *Optics of Spherical Particles*, Ph.D. thesis, University of Utrecht (J. F. Duwaer & Sons, Amsterdam, 1946).

E3. Sodium *D*-Lines Intensity Ratio from Optically Dissociated NaI.* HOWARD G. HANSON, *University of Minnesota, Duluth.*—The intensity ratio D_2/D_1 for the sodium doublet has been measured for radiation from excited sodium atoms which result from the optical dissociation of NaI vapor by ultraviolet light in the 2000–2450 A region. With shorter wavelength ultraviolet as exciting source the D_2/D_1 ratio is approximately 1.0 and with the longer wavelengths the ratio is approximately 1.5. Addition of foreign gases such as argon or water vapor cause the D_2/D_1 ratio to increase to approximately 1.8. Cross sections for the transfer of excited sodium atoms from the $3^2P_{\frac{1}{2}}$ to the $3^2P_{\frac{3}{2}}$ and vice versa have been measured as they depend on the relative velocity of the excited sodium atoms with respect to the foreign gas atoms or molecules. The velocity of the excited sodium atoms is varied by using different wavelengths of ultraviolet light as exciting sources. Measurements were made with a photomultiplier tube. The sodium doublet was resolved with a reflection grating monochromator.

* Supported in part by the Office of Ordnance Research.

E4. Mean Life of the $^3P_2$ Metastable Argon Level.* F. A. GRANT AND A. H. FUTCH, JR.,† *University of Maryland.*—Using a previously described optical absorption technique,[1] the mean life of the $^3P_2$ argon level has been measured as a function of pressure in pure argon at 77°K and at 300°K. The collision coefficient for quenching of metastable atoms by three-body collisions appears to decrease with increasing temperature, and as expected, the two-body collision coefficient increases. At constant density the ratio of the diffusion coefficient at 300°K to the value at 77°K is considerably greater than the $T^{\frac{1}{2}}$ dependence obtained from simple hard sphere kinetic theory. In neon-argon mixtures, the three-body collisions disappear and the two-body collision coefficient decreases asymptotically to a new value as the ratio of the partial pressures neon:argon is increased.

* Work supported by the U. S. Bureau of Ships.
† Now with E. I. du Pont de Nemours & Company, Savannah River, South Carolina.
[1] F. A. Grant and A. D. Krumbein, Phys. Rev. **90**, 59 (1953).

E5. Decay of the Metastable Levels of Neon.* J. R. DIXON AND F. A. GRANT, *University of Maryland.*—The current and pressure dependence of the decay of the $^3P_0$ metastable level in neon was measured using an absorption method. The decay was found to be nonexponential and current dependent at at normal excitation currents. At extremely low excitation current, however, the $^3P_0$ decay became exponential and current independent. The mean lives associated with such exponential decays were measured as a function of pressure. The results are in agreement with the usual theoretical relation based on metastable destruction by diffusion to the container walls at low pressures and two-body collisions at high pressures. The pressure dependence of the $^3P_2$ level was also studied. It was found, as previously reported by Grant,[1] that the experimental results for the pressure range from 2 to 20 mm of Hg, where diffusion loss is small, do not agree with the usual theoretical prediction. Experimental evidence will be presented to show that the results are in agreement with the theoretical relation recently proposed by Phelps.[2]

* Work supported by the U. S. Bureau of Ships.
[1] F. A. Grant, Phys. Rev. **84**, 844 (1951).
[2] A. V. Phelps, Bull. Am. Phys. Soc. **30**, No. 3, 31(A) (1955).

E6. Analysis of Atomic Spectra with Electronic Digital Computers. K. G. KESSLER, S. B. PRUSCH, AND I. A. STEGUN, *National Bureau of Standards.*—A code has been prepared to find energy levels in complex atomic spectra with the National Bureau of Standards electronic digital computer, the SEAC. The measured wavelengths of atomic lines are first converted to vacuum wave numbers. Differences between known energy levels are then put into the computer, and all pairs of spectrum lines whose wave numbers show these differences are listed.

A list of predicted levels is then prepared by adding the wave number of one of the line pairs to one of the known energy levels associated with the same difference. The lists of predicted levels compiled from a number of differences are then merged and put in order of increasing values. All values which occur only once in this list are presumed to be fortuitous coincidences and are rejected. The reality of the remaining levels is tested by the combination principle. Application of these calculations to the analysis of the first spectrum of ruthenium will be discussed.

Invited Paper

E7. The Hyperfine Structure of the Zeeman Effect and Isotope Shift in the Spectrum of Indium. DEREK JACKSON, *Laboratoires de Bellevue.*

MONDAY AFTERNOON AT 2:00

Terrace Room

(R. M. BOZORTH presiding)

Ferromagnetics

EA1. Curie Temperature-Composition Curves of Ferrite Compounds. H. A. BROWN, *National Carbon Company and the University of Miami.*—The dependence of the Curie temperature, T_c, on the composition variable, x, for binary compounds of ferrimagnetic materials has been investigated using the molecular field theory of Néel, the Bethe-Peierls-Weiss method, and the Kramers-Opechowski method. The general conclusion is that it is possible to obtain some information about the structure of these compounds from the observed T_c-x curves. The substances investigated were the 15 compounds of the six general ferrospinels with the chemical formulas: NOM_2O_3, $NOMNO_3$, NON_2O_3, MON_2O_3, $MONMO_3$, MOM_2O_3, where N is a nonmagnetic and M a magnetic ion. The resulting equations relating T_c and x show considerable structure dependence. For example, the molecular field theory results for the compounds $(NOMNO_3)_{1-x}(NOM_2O_3)_x$, $(MONO_3)_{1-x}$ $(NOMNO_3)_x$, and $(MONMO_3)_{1-x}(MON_2O_3)_x$ show that T_c should be proportional to O, $[x(1-x)]^{\frac{1}{2}}$, and $(1-x)^{\frac{1}{2}}$, respectively, if only $A-B$ interaction is included ($\alpha=\beta=0$ in Néel's notation). The results of the B–P–W method (with the same restriction to $A-B$ exchange) are similar, but, in general, predict more rapid variations of the Curie temperature, in better agreement with the observed curves. Results of the K–O method, which are still incomplete, will also be discussed.

EA2. Hall Effect in Fe_3O_4 and $(NiO)_{0.75}$ $(FeO)_{0.25}$ (Fe_2O_3).† JEROME M. LAVINE,* *Harvard University.*—Measurements of the ordinary Hall coefficient of a synthetic crystal[1] of Fe_3O_4 and of a synthetic single crystal[2] of $(NiO)_{0.75}$ $(FeO)_{0.25}$ (Fe_2O_3) have been made at room temperature. The charge carrier concentration of Fe_3O_4 deduced from this measurement, of the order of $\frac{1}{4}$ electron per Fe_3O_4 molecule, is roughly in accord with Verwey's[3] hypothesis and suggests that the low conductivity of Fe_3O_4 compared with a metal may be attributed to a low mobility. The carrier concentration of $(NiO)_{0.75}$ $\times(FeO)_{0.25}$ (Fe_2O_3) is roughly $\frac{1}{10}$ electron per Fe_3O_4 molecule. The Hall mobility for Fe_3O_4 is of the order of 0.5 cm²/volt-sec while the mobility for $(NiO)_{0.75}$ $(FeO)_{0.25}$ (Fe_2O_3) is about 0.05 cm²/volt-sec. An activation energy deduced from conductivity data has been associated with the charge carrier density in these materials and a very crude model of mobility is used to compare their conductivities.

† The research reported here was supported jointly by the U. S. Navy Department, the U. S. Signal Corps, and the U. S. Air Force under Office of Naval Research Contract N5ori-76 Task Order 1.

* Now at Research Division, Raytheon Manufacturing Company.

[1] Grown by J. Smiltens, Laboratory for Insulation Research, Massachusetts Institute of Technology.

[2] Grown by G. W. Clark, Linde Air Products Company.

[3] E. J. W. Verwey and P. W. Haayman, Physica **8**, 979 (1941).

EA3. Anomalous Microwave Absorption in Ferrites Below Magnetic Saturation. R. C. LECRAW AND E. G. SPENCER, *The Diamond Ordnance Fuze Laboratories.*—Perturbation methods are used to measure the six components of intrinsic tensor permeability[1] (μ) at X-band as functions of internal, dc magnetic field. The samples are thin axial rods in a degenerate TM_{110} transmission cavity. For single domains, assuming Landau-Lifshitz or Bloch type damping, the loss term for a positive circularly polarized field (h_+) is greater than that for a negative circularly polarized field (h_-). One expects this also for a large assembly of domains such as a partially saturated rod. However, it is found for nickel ferrite over most of the magnetization curve that the h_+ loss term, $\mu_+''=\mu''+K''$, is less than the h_- loss term, $\mu_-''=\mu''-K''$; hence K'' is negative.[2] (For dc fields above several hundred oersteds, the absorption is normal with $\mu_+''>\mu_-''$.[1]) The $\mu_+''<\mu_-''$ indicates that smaller domains, whose magnetization vectors average >90° with the dc field and in which an applied h_- appears as h_+, have proportionately greater losses than larger domains. Mechanisms to produce this effect are discussed.

[1] Convention Record, Inst. Radio Engrs. (1955), Part 8, pp. 113–121.

[2] Rado has shown that a positive energy loss requires only that $|K''|<\mu''$. U.R.S.I., Michigan Symposium, June, 1955 (to be published).

EA4. Magnetic Properties of Some Nickel Ferrite Single Crystals. T. R. MCGUIRE AND L. R. MAXWELL, *U. S. Naval Ordnance Laboratory.*—In the following table are listed g-values and anisotropy constants (K_1) measured by ferrimagnetic resonance (9500 mc), as well as the magnetic moment per molecule (μ_B) and Curie temperature (T_c) of several nickel ferrite single crystals:

Crystal	μ_B	T_c°K	(g	K_1) 300°K	(g	K_1) 77°K
a	2.63	873	2.12	-4.27×10^4	2.07	-6.33×10^4
b	2.69	869	2.19	-4.23×10^4	2.39	-7.48×10^4
c	2.27	873	2.17	-3.32×10^4	2.26	-1.96×10^4
d	2.44	871	2.23	-3.72×10^4	2.24	-2.83×10^4
e	2.23	871	2.35	-3.03×10^4	2.66	-4.13×10^4

Crystal *a* (approximate formula $Ni_{0.72}Fe_{0.20}Co_{0.08}Fe_2O_4$) from Rutgers Ceramic Laboratory was also studied by H. Shenker[1] who found $K_1=-4.1\times10^4$ (300°K) and $K_1=-2.8\times10^4$ (77°K) by torque methods. Crystal *b* from Linde Air Products Company contained even a greater excess iron content. The others, *c*, *d*, and *e* were grown by E. J. Scott of this Laboratory; by chemical analysis *c* and *d* showed an excess of 0.15 divalent iron while *e* had 0.11 divalent iron.

Certain ambiguities in the interpretation of the above data will be discussed.

[1] H. Shenker, thesis, University of Maryland, 1955.

EA5. Cation Distributions in Ferrospinels. I. Theoretical. S. E. HARRISON, *Remington Rand Univac*, H. B. CALLEN, *University of Pennsylvania*, AND C. J. KRIESSMAN, *Remington Rand Univac.*—The distributions of cations within a ferrospinel lattice is related to the functional dependence of energy and entropy on ionic configuration. Néel[1] and Smart[2] have each given preliminary treatments of the problem, concerning themselves solely with the dominant permutational contribution to the entropy. The remaining terms in the entropy, and the various energy terms, remain implicitly within their treatment with unknown temperature dependence. Interpretation of experimental data on the basis of the predicted distribution equations can be done only by the arbitrary assignment of a specific temperature dependence to these terms. We have consequently undertaken a fully explicit development of the statistical thermodynamics underlying the distribution of cations in ferrospinels. In addition to the permutational contribution to the entropy the distribution depends upon the nonthermal portion of the thermodynamic internal energy (u_1), and upon various other terms which appear to be relatively small. Although the dominant contribution to u_1, the Madelung energy, is understood quantitatively, the remaining terms are as yet unanalyzed. The derived distribution law can be applied to the interpretation of experimental data with a minimum of *ad hoc* assumptions.

[1] L. Néel, Compt. rend. **230**, 190 (1950).
[2] J. S. Smart, Phys. Rev. **94**, 847 (1954).

EA6. Cation Distribution in Ferrospinels. II. Magnesium-Manganese and Magnesium-Nickel Ferrites. C. J. KRIESSMAN AND S. E. HARRISON, *Remington Rand Univac.*—In order to compare experimental data with the general theoretical analysis of the distribution of cations within a ferrospinel lattice developed in the previous paper, the saturation magnetization of two systems of ferrites, $Mg_yMn_{1-y}Fe_2O_4$ and $Mg_yNi_{1-y}Fe_2O_4$ have been measured. All the compounds were sintered at 1400°C and quenched from various temperatures ranging from 1400°C to 400°C. Each compound exhibits a change in magnetic moment with quench temperature which is primarily due to the varying population of A sites by Mg ions. The fraction of Mg ions on A sites, η, is evaluated in the light of several assumptions about the positioning of the Mn and Ni ions. From this data it is shown that the nonthermal portion of the thermodynamic free energy, u_1, depends quadratically on η.

EA7. Superexchange Mechanism in Antiferromagnetic Oxides.* R. K. NESBET, *Lincoln Laboratory.*—Previous discussions of the superexchange mechanism, which couples magnetic moments of paramagnetic ions through configuration interaction involving an intervening closed-shell ion, have recently been criticized by Pratt,[1] who points out that only configurations involving the excitation of two electrons can affect a stabilization of the antiferromagnetic coupling relative to the ferromagnetic coupling. Detailed consideration of this mechanism, in the light of a general theory of configuration interaction,[2] indicates that it will always lead to relative stabilization of the antiferromagnetic coupling, and provides a simple formula for the energy of stabilization. Applied to the antiferromagnetic oxides MnO, FeO, CoO, and NiO, this analysis leads to an approximate formula for the Néel temperatures as a function of the ionization potentials of the paramagnetic ions, the lattice constants, and a three-center integral over Wannier functions. Good agreement with experiment is found for a reasonable value of the three-center integral, which is treated as an empirical parameter but is assumed to have the same value for all four oxides.

* Supported jointly by the U. S. Army, U. S. Navy, and U. S. Air Force under contract with the Massachusetts Institute of Technology.
[1] G. W. Pratt, Jr., Phys. Rev. **97**, 926 (1955).
[2] R. K. Nesbet, Proc. Roy. Soc. (London) **A230**, 312 (1955).

EA8. Ferromagnetism of Alloys. I. A Generalized Ising's Model Approach. HIROSHI SATO, *Westinghouse Research Laboratories.*—The addition of alloying elements to pure ferromagnetic metals causes a change not only in the magnetic moment, but also in the M_s/M_0 *vs* T/Θ, $1/\alpha$ *vs* T/Θ curves, which are very much similar to one another among pure ferromagnetic elements. Interpretations of the dependence of magnetic moments upon alloying elements, including the so-called anomalous behavior of atomic moments in some alloy series, should be correlated to these changes. As a first step towards understanding this problem, the relation between the change in susceptibility above the Curie point and the change in the Curie point itself was calculated on the basis of a generalized Ising model of ferromagnetism and an extension of the Bethe-Easthope method of treatment. The results are easily visualized in the case of a dilute solution. Because of the difference in interaction between the magnetic moments of different atoms, both Curie point and susceptibility change due to the addition of other elements. In the expression for susceptibility, however, one other term appears to which there is no counterpart in the expression for the Curie point. This means, roughly speaking, that though the change of Curie point is due mostly to the change in the average interactions between atomic magnetic moments, susceptibility is much more sensitive to their local interaction.

EA9. *N*-Particle Exchange Model. JEROME I. KAPLAN, *U. S. Naval Research Laboratory.*—The *ad hoc* Hamiltonian,

$$g\mu \sum_{L=1}^{N} H_0\sigma_{zi} - 2J/N \sum_{i>j} \sigma_i\cdot\sigma_j$$

where H_0 is the applied magnetic field, J is an exchange integral, and N is the number of interacting particles, can be shown classically to give the Weiss model for ferromagnetism. The conventional energy levels and degeneracies can also be obtained quantum mechanically enabling one to calculate an exact partition function for the system. In the limit of large N one again obtains the Weiss result for the magnetization. From the classical analogy one would suppose a Hamiltonian with $\sigma_i\cdot\sigma_j$ replaced by $\sigma_{iz}\sigma_{jz}$ would also give the Weiss model for large N; this is verified quantum mechanically. It is reasoned that the nondependence of the Weiss result on the off-diagonal elements $\sigma_{x1}\sigma_y$ is what leads to its deviation from the $T^{\frac{3}{2}}$ law at low temperatures. The method of solving for the energy levels and degeneracies of the Hamiltonian will appear in a Naval Research Laboratory report.

EA10. Ferromagnetic-Antiferromagnetic Transitions in Dysprosium.* T. J. HENDRICKSON AND J. M. KELLER, *Iowa State College.*—The magnetic behavior[1,2] and specific heat[3] of dysprosium suggest that it is ferromagnetic below 85°K, antiferromagnetic between 85 and 176°K. We have studied the theory of ferromagnetic-antiferromagnetic transitions in the hexagonal close-packed structure, using the molecular field approximation and assuming that the molecular field coefficients vary slowly with temperature.[4] Our model predicts a large anisotropy in the antiferromagnetic region, with $\chi_{\parallel}$ decreasing normally and $\chi_{\perp}$ increasing to infinity as the temperature decreases toward 85°K. The predicted experimental χ for a polycrystalline sample, an average of $\chi_{\parallel}$ and $\chi_{\perp}$, agrees qualitatively with experiment. We have also studied the effect of external magnetic fields. Moderate fields applied nearly parallel to the preferred axis cause the phenomenon of spin flop (sudden change of spin directions). Rather larger

magnetic fields change the antiferromagnetic arrangement into one of paramagnetic saturation.

* Work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.
[1] F. Trombe, Compt. rend. **236**, 591 (1953).
[2] Elliott, Legvold, and Spedding, Phys. Rev. **94**, 1143 (1953).
[3] Griffel, Skochdopole, and Spedding, J. Chem. Phys. (to be published).
[4] J. S. Smart, Revs. Modern Phys. **25**, 327 (1953).

EA11. Basis of the Domain Structure Variational Principle.* T. L. GILBERT AND H. EKSTEIN, *Armour Research Foundation.*—The physical theory of domains is based on a variational principle which states that the stable magnetization fields are those for which the domain energy is a minimum with respect to arbitrary variations in the direction of the magnetization field at any point.[1,2] It will be shown that this variational principle can be derived from the variational principle of quantum mechanics if the wave function is chosen to be a Slater determinant constructed from localized one-electron functions with arbitrarily oriented spin functions. This derivation is valid for the ground state at 0°K. The generalization to nonlocalized orbitals and to higher temperatures will be discussed.

* Work supported by the Indiana Steel Products Company, Valparaiso, Indiana.
[1] F. Bloch, Z. Physik **61**, 206 (1932).
[2] L. Landau and E. Lifshitz, Physik. Z. Sowjetunion **8**, 153 (1935).

EA12. Reversible Susceptibility Assuming Domain Rotation. D. M. GRIMES, *University of Michigan.*—The reversible susceptibility both parallel and normal to the dc magnetization has been calculated as a function of magnetization for a polycrystalling ferromagnetic specimen by assuming the Landau-Lifschitz differential equation to be applicable to each crystallite, and by using as a distribution function describing the normalized volume of the material with its moment making an angle θ with the dc field as a function of magnetization that given by Brown.[1] The result is an extension of the work of Grimes and Martin[2] to include rotational susceptibility. The equations for isotropic symmetry are

$$\chi_{rp}=3\chi_0\frac{L(\eta)}{\eta}, \quad \chi_{rt}=\tfrac{3}{2}\chi_0\left[1-\frac{L(\eta)}{\eta}\right],$$

where η is defined by $M=M_sL(\eta)$ and $L(\eta)=ctnh\eta-1/\eta$. χ_0 is a constant only if the effective anisotropy field is much larger than the applied dc field, and goes to zero as $1/H$ for large H.

[1] W. F. Brown, Jr., Phys. Rev. **52**, 325 (1937); Phys. Rev. **54**, 279 (1938).
[2] D. M. Grimes and D. W. Martin, Phys. Rev. **96**, 889 (1954).

MONDAY AFTERNOON AT 2:00

Boston Room

(H. M. FOLEY presiding)

Theoretical Physics, II

F1. Phonon-Polaron Scattering in Path Integral Formalism.* T. D. SCHULTZ, *M.I.T.*—Following a suggestion by Feynman the scattering amplitude in phonon-polaron scattering has been calculated for all coupling strengths. We have replaced the true action for the propagation of a free polaron (phonon-clothed electron) with Feynman's approximate action[1] in Feynman's general path integral formulation of the interaction of a particle and a field.[2] The effect is to take into account in an approximate way all virtual phonons rather than to consider only one or two exactly. It is found that although the path integral formalism deals with velocities rather than momenta, the need for knowledge of the polaron mass is not thereby circumvented. However, in the first approximation a natural momentum conservation law provides the required knowledge. Higher approximations introduce difficulties not usually encountered when the first approximation is the scattering of a bare particle. Comparisons have also been made with perturbation theory and the work of Low and Pines in the weak coupling region and with the work of Pekar in the strong coupling region.

* Supported by the National Science Foundation.
[1] R. P. Feynman, Phys. Rev. **97**, 660 (1955).
[2] R. P. Feynman, Phys. Rev. **80**, 440 (1950).

F2. Self-Energy of the Polaron at Intermediate Temperatures. THOMAS FULTON,* *Institute for Advanced Study.*—We employ the Hamiltonian which is used as a model to represent the behavior of an electron coupled to the optical modes of an ionic crystal.[1] Approximate eigenvalues of this Hamiltonian are obtained for temperatures at which real phonons are present in the field. The method used is an extension of the variational technique employed by Gurari[2] to obtain the eigenvalues at absolute zero. The trial wave functions employed in the present problem allow for the change of the occupation number of any phonon mode by at most unity (one virtual absorption or emission per mode in intermediate states). Correlations between phonons are neglected. The eigenvalues obtained indicate that an electron in equilibrium with the lattice will have a strongly temperature-dependent effective mass. They reduce to the perturbation theory results in the limit of small coupling, and are identical with the intermediate coupling solutions[2,3] obtained in the limit of $T=0$°K.

* National Science Foundation Postdoctoral Fellow. This work was performed while the author was a summer visiter at the General Electric Research Laboratory.
[1] H. Frohlich, Advances in Phys. **3**, 325 (1954).
[2] M. Gurari, Phil. Mag. **44**, 329 (1953).
[3] Lee, Low, and Pines, Phys. Rev. **90**, 297 (1953).

F3. Collective Oscillations in a System of Interacting Particles. DAVID PINES, *Princeton University.*—The methods developed for the collective description of electron interactions[1] may be extended in straightforward fashion to describe a general system of particles interacting via effectively repulsive two-body forces. The resultant formulation turns out to be particularly appropriate for systems for which the low-lying collective oscillations are sound waves. The dispersion relation for the longitudinal collective oscillations is $\omega^2(k)=nk^2V_k/m$, where n and m are the density and mass of the particles, and V_k is the kth Fourier component of the interaction potential. In the long wavelength limit, V_k is generally independent of k, and the dispersion relation reduces to the usual sound wave dispersion relation. The criterion that the collective approach be applicable is that the effective coupling between the sound waves and the individual particles be small, and this criterion may be shown to be identical with the usual criterion for the existence of sound waves, namely that the root-mean-square particle velocity be small compared

to the velocity of sound. The applicability of this approach to many-body problems of current interest, e.g. liquids, nuclei, and superfluidity, will be discussed.

[1] D. Bohm and D. Pines, Phys. Rev. **92**, 609 (1953).

F4. Role of Quantum Statistics in the Collective Approach to the Many Body Problem.* JEROME K. PERCUS AND GEORGE J. YEVICK, *Stevens Institute of Technology.*—If one uses collective coordinates for the many body problem, the Schroedinger equation in the collective coordinate representation contains no reference to the type of quantum statistics of the system. For the Einstein-Bose case, regularity at infinity is sufficient to satisfy the symmetry requirements inasmuch as the coordinates are themselves symmetric; however, in perturbation calculations, realization of the finiteness of collective coordinate space is crucial. The problem of Fermi-Dirac particles without spin is readily solved: the wave function is required to vanish at the "mean" boundary of collective coordinate space. The resulting energy spectrum for low wave number is the same to zeroth order as that for E.B. statistics, but large deviations occur for high wave number. The introduction of spin, even in the absence of spin interaction, gives rise to qualitatively new features, necessitating the use of two sets of collective coordinates, each obeying F.D. statistics. To the extent that these two sets can be regarded as independent, the effect of spin manifests itself as a strictly additive term to the specific heat, etc., but this additive term depends on the configuration space correlation function.

* Supported by the Office of Naval Research.

F5. Dependence of Dipole Matrix Elements upon the Upper State Wave Functions. R. E. MEYEROTT, *The RAND Corporation.*—The dependence of the dipole matrix element $I_{nl}^{n'l'} = \int_0^\infty R_{nl} r R_{n'l'} dr$ upon the upper state wave functions is often desired for qualitative work. For the photoelectric effect, for example, the temptation is to use a reasonably good wave function for the initial state but perhaps Bessel functions for the free states. When one deals with wave functions that are solutions of the radial equation for the same potential, the sum rule $\Sigma_{n'}[I_{nl}^{n'l'}]^2 = \int_0^\infty R_{nl} r^2 R_{nl} dr$ is valid and shows that the choice of the final state function determines only the distribution of I^2 and not its sum. This dependence can be seen clearly in the case of the $1s \rightarrow n'p$ photoelectric effect from the ground state of hydrogen where $\Sigma_{n'} I^2 = 3$. Using Coulomb upper state wave functions, the first state lies at an energy of $\frac{3}{4}$ above the ground state while for Bessel functions, the first state is at an energy 1. For Coulomb functions ΣI^2 over continuum is only 0.849, while for Bessel functions the entire sum lies in the continuum and must be 3. The exact distribution will be shown.

F6. The Perturbed Hartree-Fock Equations and the Polarizability of Atoms and Ions.* LELAND C. ALLEN, *M.I.T.*—The polarizability of isolated atoms and ions is considered from the Hartree-Fock standpoint. The equation for the uniform field and also for a more general perturbing potential are given for several orders in the perturbation expansion parameter λ. For the uniform field polarizability the resulting relations are compared with the work of Sternheimer[1] and others and with the experimental data on the refractive index of ionic crystals. The present method gives the equations for determining the perturbed functions directly and appears to have a calculational advantage over similar relations obtained by Peng.[2]

* Supported in part by the Office of Naval Research.
[1] R. M. Sternheimer, Phys. Rev. **96**, 951 (1954).
[2] H. W. Peng, Proc. Roy. Soc. (London) **A178**, 499 (1941).

F7. Atomic Scattering Factors Calculated from the Statistical Model With Exchange. L. H. THOMAS AND K. UMEDA, *Watson Scientific Computing Laboratory.*—Radial Fourier transforms have been computed of the statistical charge distributions, recently published by one of us,[1] which include the effects of exchange. These transforms provide atomic scattering factors which agree qualitatively with those calculated from Hartree-Fock consistent field calculations[2] which also include exchange for atomic numbers 18 and 20, and may therefore be expected to be useful for any larger atomic number. The diamagnetic susceptibility computed as a by product varies more smoothly with atomic number than the individual values previously given by Jensen. Evaluations for all integral atomic numbers for neutral atoms and for degrees of ionization one to four are in progress.

[1] L. H. Thomas, J. Chem. Phys. **22**, 1758 (1954).
[2] Berghuis, Haanappel, Potters, Loopstra, MacGillavry, and Veenandel, Acta Cryst. **8**, 445 (1955).

F8. Hylleraas Type Wave Functions for the Ground State of Helium.* H. M. SCHWARTZ, *University of Arkansas.*—Incidental to an investigation of Ritz-variational approximations to the ground state solution of the nonrelativistic helium wave equation, expansions of the Hylleraas type involving half-integral powers were studied and found to be advantageous in some applications. A report of similar solutions for the negative hydrogen ion has been made recently.[1] Our normalized 4-term and 6-term functions are (atomic units):

$$\exp(-1.8070s)\,[1.22323+0.22927u^{\frac{1}{2}}+0.17392t^2+0.25168u]$$

$$\exp(-1.75000s)\,1.401276+0.380444u^{\frac{1}{2}}+0.153910t^2$$
$$+0.144767u-0.366021s^{\frac{1}{2}}+0.051416s].$$

The corresponding energies are -2.90277 a.u., and -2.90338 a.u. The latter value compares favorably with Hylleraas' 6-term result, -2.90324 a.u. Preliminary results with higher-term expansions are also encouraging.

* This work is supported in part by the U. S. Atomic Energy Commission.
[1] Levitt, Tauber, and Wu, Bull. Am. Phys. Soc. **30**, No. 4, 33 (1955).

F9. *L*-Shell Ionization by Protons. E. MERZBACHER, H. W. BREWER, AND T. REEVES, *University of North Carolina.*—Using the formulas derived by Walske[1] in the Born approximation, we have computed the cross section for ionization of the *L*-shell of heavy atoms by impact of heavy charged particles in the Mev energy range. Conparison with experiments[2] on *L*-shell x-rays produced by protons from 1.5 to 4 Mev on Ta, An, Pb, and U shows satisfactory agreement. The dependence of the calculated cross section on energy, atomic number, and outer screening will be exhibited and found in accord with experiment. It should be noted that the velocity of the *L*-shell electrons is of the same order of magnitude as the velocity of the incident particle.

[1] M. C. Walske, Cornell thesis, 1951.
[2] E. M. Bernstein and H. W. Lewis, Phys. Rev. **95**, 83 (1954).

F10. Transmission and Reflection in a Disordered Linear Chain of Potential Wells. PETER L. AUER, *General Electric Research Laboratory.*—We consider a linear chain of identical square wells arranged at random intervals and ask for the density of energy levels associated with single particle stationary states. Focusing on the positive energy continuum we first look for the possible existence of stop bands and pass bands for a semi-infinite chain. We seek an analytic method of solution, alternative to the "node counting" scheme[1] previously employed, with the expectation that a generalized statistical treatment may be adapted. The procedure adopted here is as follows. The problem of proper fitting of solutions to the wave equation within the chain is reduced to the

solution of a set of second-order difference equations. Specification of either the transmission or reflection coefficient leads to an eigenvalue problem for the difference equation, with the above scattering coefficients considered as parameters. In order to demonstrate the existence of stop bands, for instance, we are required to solve a determinantal equation containing random variables related to the random spacing of wells in the chain. If we specify the chain configuration by assigning a probability distribution to the random variables, we are led to a problem analogous to one previously solved by Dyson.[2] The formalism developed here is readily generalized to a chain of scattering centers other than square well potentials.

[1] R. Landauer and J. C. Holland, J. Chem. Phys. **22**, 1655 (1954).
[2] F. J. Dyson, Phys. Rev. **92**, 1331 (1953).

TUESDAY MORNING AT 9:30

Manhattan Center, Gold Room

(R. L. SPROULL presiding)

Symposium of the Division of Electron Physics

G1. Emission Spectra Excited by Electronic and Ionic Impact. C. Y. FAN, *Yerkes Observatory.* (30 min.)

G2. Photoionization in Gases. G. L. WEISSLER, *University of Southern California.* (30 min.)

G3. Determination of Oscillator Strengths from Collision Cross Sections of Atmospheric and Other Gases. E. N. LASSETTRE, *Ohio State University.* (30 min.)

Business Meeting of the Division of Electron Physics

(To be intercalated in the Symposium at such time as may seem good to the Chairman)

Contributed Papers in Electron Physics

G4. 3.3- to 5-mm Wavelength Microwave Diagnostic Studies of Pulsed Gaseous Discharges. R. F. WHITMER, *Los Alamos Scientific Laboratory.*—A microwave interferometer has been used successfully to study ionization rates, electron-particle collision frequency and diffusion rates in pulsed gaseous discharges. Densities up to 10^{11} electrons/cc have been measured as a function of time. A simultaneous measurement of the electron-particle collision frequency has been obtained along with a measurement of the diffusion rate. A measurement of the recombination coefficient α has also been obtained for several gases. Studies of the above quantities have been made as a function of time and electron density. Various types of discharge tubes have been examined. A specific example of a discharge tube containing hydrogen at a pressure of 100 microns will be given.

G5. Collective Coordinates Applied to Ions in a Plasma. A. A. BROYLES, *The RAND Corporation.*—Bohm and Pines have employed the coefficients ρ_k in the Fourier series expansion of the charge density as independent coordinates to treat an electron gas. These coördinates have also been used[1] in the problem of determining, by classical mechanics, the probability $P(\epsilon)$ of finding an electric field of magnitude ϵ on an ion in a plasma where the charges on the electrons have been smeared into a uniform negative background. In both these treatments, subsidiary conditions relating the ρ_k's to the particle positions ($\mathbf{r}_j$'s) have been ignored. The present paper determines $P(\epsilon)$ in a manner not requiring these subsidiary conditions. The limitation on the number of collective coordinates has been found by requiring the collective contribution to determine $P(\epsilon)$ completely for small fields. The short-range interaction between particles may be written approximately as $r^{-1}-f(\theta)+g(\theta)r^2$ where θ is the temperature and the ions have unit charge. The functions, f and g, have been determined. The $P(\epsilon)$ obtained agrees well numerically with the Holtsmark distribution at infinite temperature.

[1] A. A. Broyles, Phys. Rev. **100**, No. 2 (1955).

G6. Incidence of an Electromagnetic Wave on a "Čerenkov Electron Gas." MURRAY A. LAMPERT, *RCA Laboratories.*—An electron gas moving in vacuum, if sufficiently dense, acts like a mirror to an incident em (electromagnetic) wave. A "Čerenkov electron gas," that is, an electron gas moving through or sufficiently close to a slow-wave medium at a velocity exceeding that of an em wave in the medium cannot, in the conventional sense, reflect the wave. No matter how high the electron density, the incident em fields penetrate the electron gas with no reactive attenuation. An analysis of this problem has been made for a simplified one-dimensional model and it reveals that above a critical density a Čerenkov electron gas does exhibit a "mirror-like" quality; namely, it does reverse, inside the gas, the direction of propagation of an em wave incident upon it.

G7. Experimental Determination of Charge Transfer Cross Section. S. N. GHOSH AND W. F. SHERIDAN, *Air Force Cambridge Research Center.*—The method utilized by the authors[1] for determining charge transfer cross sections has been improved and applied to symmetric and unsymmetric reactions involving the inert gases, N_2 and H_2. The cross sections were found to be about 20% higher than the values obtained by previous investigators.[1,2] The discrepancy can be explained by the fact that previous workers did not take into account the secondary electrons impinging on the plate where the charge transfer ions are collected. As expected from Massey's theory[3] the reactions involving mixtures of gases (having nearly equal ionization potentials) were found to have maximum cross sections for low energy ions. It was also observed that the cross sections are more dependent on the incident ions than on the bombarded atoms or molecules. The secondary electron emission due to ion bombardment of metal surfaces can also be measured by this method. The results for a brass surface agrees well with the values[4] for Cu.

[1] Dillon, Sheridan, Edwards, and Ghosh, J. Chem. Phys. **23**, 776 (1955).
[2] J. B. Hasted, Proc. Roy. Soc. (London) **A205**, 421 (1951); **212**, 235 (1952); J. B. H. Stedeford, and J. B. Hasted, Proc. Roy. Soc. (London) **A227**, 466 (1955); R. F. Potter, J. Chem. Phys. **22**, 974 (1954).
[3] H. S. W. Massey, Repts. Progr. Phys. **12**, 248 (1949).
[4] A. Rostagni, Z. Physik **88**, 55 (1934).

G8. Charge Changing Collisions of Helium Ions in Gases.* S. K. ALLISON, J. CUEVAS,† S. KRASNER, AND P. G. MURPHY, *University of Chicago.*—When an ion beam is traversing a circular orbit in an attenuated gas in an intense magnetic field, an ion is lost from the beam's orbit if it changes its charge in an encounter with a gas atom. From the observed attenuation of the beam, cross sections representing the total probability of charge changing collisions can be computed. If σ_{ij} is such a cross section, i representing the initial and j the final positive ionic charge, the total attenuation cross sections for helium ions are: He^{++}, $(\sigma_{21}+\sigma_{20})$; He^{+}, $(\sigma_{10}+\sigma_{12})$; He^{0}, $(\sigma_{01}+\sigma_{02})$. Separated beams of He^{++}, He^{+}, and He^{0} of kinetic energies 100–450 kev were obtained by charge equilibration of a He^{+} beam from a Cockcroft-Walton accelerator and subsequent passage through a magnetic field. Combining the observed total attenuation cross sections with known equilibrium values of the charge composition of a helium ion beam, plus reasonable assumptions, permits computation of the individual σ's. Capture and loss cross sections for the three charge states of helium ions, in the kinetic energy range 100–450 kev, will be presented for the gases hydrogen, helium, and air.

* Work supported in part by the U. S. Atomic Energy Commission.
† Now at Junta de Energia Nuclear, Madrid, Spain.

TUESDAY MORNING AT 9:30

Grand Ballroom

(C. P. BROWNE presiding)

Reactions of Transmutation and Nuclear Energy Levels, Mg through Si

GA1. Gamma Radiation from $Mg^{24}(p,\gamma)Al^{25}$. G. A. BARTHOLOMEW, H. E. GOVE, A. E. LITHERLAND, AND E. B. PAUL, *Chalk River Laboratories.**—The angular distributions of the γ rays to the ground state and to the second excited state have been measured in detail at the Al^{25} resonance at $E_p=1.66$ Mev, and confirm the $5/2+$ assignment previously reported.[1] An $E2$ transition to the first excited state is observed. Following the rotational interpretation of the Al^{25} levels as described in the following paper, a search was made for weak resonances which may have been missed in earlier yield curves. In particular, a level expected near 3.6-Mev excitation was searched for and found at 3.44 Mev. This level decays weakly to the ground state and more strongly by a two-step cascade through another previously unobserved level at 1.61 Mev. Assignments of spin and parity cannot be made unambiguously, but the angular distributions of the 3.44-, 1.83-, and 1.61-Mev γ rays and the decay scheme strongly suggest $9/2+$ and $7/2+$ for the 3.44- and 1.61-Mev states, respectively. The 1.61-Mev level may be the mirror of the level at the same energy in Mg^{25}.

* Placed next to GA2 at speaker's request.
[1] G. A. Bartholomew *et al.*, Phys. Rev. **99**, 1649(A) (1955).

GA2. Gamma Rays from $N^{14}(n,\gamma)N^{15}$, $F^{19}(n,\gamma)F^{20}$, and $Mg(n,\gamma)$. P. J. CAMPION AND G. A. BARTHOLOMEW, *Chalk River Laboratories.*—Gamma rays from these reactions were reinvestigated with an improved pair spectrometer. In N^{15}, in addition to γ rays previously observed,[1] new γ rays at 9.03 ± 0.03, 8.54 ± 0.04, 3.67 ± 0.02, and 3.52 ± 0.02 Mev were detected, and evidence was found that the 5.3-Mev doublet levels are excited about equally in direct transitions from the capturing state. In F^{20}, γ rays at 6.599 ± 0.011 (ground state γ ray), 6.018 ± 0.011, 5.54 ± 0.02, 5.28 ± 0.02, and 5.10 ± 0.02 Mev were observed. The difference, 0.581 ± 0.013 Mev, between the first two is significantly smaller than the published[1] energy, 0.652 ± 0.008 Mev, for the first excited state. In Mg, in addition to γ rays previously observed,[2] weak γ rays at 11.086 ± 0.025 (ground state γ ray), 10.08 ± 0.02, 8.93 ± 0.02, and 8.55 ± 0.02 Mev were detected, all of which are presumably emitted from high-energy levels in Mg^{26}. The ratio of the intensities of the γ rays at 2.816 ± 0.016 and 3.408 ± 0.018 Mev which are emitted from the $3/2-$ level in Mg^{25} was remeasured and found to be 7 ± 2, in agreement with the corresponding ratio[3] in Al^{25}.

[1] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **27**, 77 (1955).
[2] Kinsey, Bartholomew, and Walker, Phys. Rev. **83**, 519 (1951).
[3] Litherland, Paul, Bartholomew, and Gove (to be published).

GA3. $O^{15}(\gamma,p\gamma')N^{15}$ and $O^{16}(\gamma,n\gamma')O^{15}$.* N. SVANTESSON,† *National Bureau of Standards* (introduced by E. Hayward).—The pulse-height distribution produced by the photons emitted by a water target irradiated by bremsstrahlung spectra has been studied as a function of the peak energy of the bremsstrahlung spectra from 16–30 Mev. The experimental arrangement was that used in the elastic scattering experiment of Fuller and Hayward. A 20 channel analyzer was used to cover the range of pulse sizes from 2–12 Mev. A peak appears in the pulse-height distribution for bremsstrahlung energies greater than 21 Mev. A comparison with the pulse-height distribution produced by the 4.43-Mev photon from a RaD-Be source gives 6.3 Mev as the energy of the photon emitted by the oxygen target. Both the energy and the threshold of this line are consistent with its resulting from the decay of the second excited states of N^{15} and O^{15} following (γ,p) and $\gamma,n)$ processes in O^{16}. It is estimated that no other lines in N^{15} and O^{15} are present in the pulse height distributions with intensities as great as 20% of that of the 6.3-Mev line. The activation curve of this line indicates that the cross section for its production peaks at about 24 Mev with a cross section of a few millibarns.

* The research was supported in part by the United States Air Force, through the Office of Scientific Research of the Air Research and Development Command.
† Supported in part by Atomkommitten, Sweden; on leave from the University of Lund.

GA4. Energy Levels of O^{18}.* NELSON JARMIE, *Los Alamos Scientific Laboratory.*—The energy levels of O^{18} have been investigated up to 6.8 Mev. The reaction $F^{19}(t,\alpha)O^{18}$ was used, with the α groups being investigated at 90° by a 16-inch double focusing magnetic spectrometer. 1.8-Mev tritons were accelerated onto an evaporated CaF_2 target by a Los Alamos 2.5-Mev electrostatic accelerator. Preliminary results give energy levels for O^{18} at 2.00, 3.59, 3.97, 5.02, 5.18, 5.32, 5.46, 6.20, and 6.34 Mev. The levels were unusually distinct and isolated due, in part, to the high Q-value of the reaction (11.847 Mev) giving very positive identification to the observed data. Runs were taken to determine the effect of any possible background or contaminant. Data on the mass of F^{21} and its energy levels was also obtained.[1] The same experimental setup will be used to investigate the reaction $F^{19}(He^3,\alpha)F^{18}$ to obtain an interesting comparison of the levels of O^{18} and F^{18} which are members of an isobaric spin triplet. Measurements of the absolute cross section and angular distribution are also planned.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] N. Jarmie, Phys. Rev. **99**, 1043 (1955).

GA5. Energy Levels in F^{18}. J. W. Butler, H. D. Holmgren, and W. E. Kunz, *Naval Research Laboratory.*—The $O^{16}(He^3,p)F^{18}$ reaction has been used to study the states in F^{18} below about 3 Mev. These states were excited by bombarding a thin NiO target with 2-Mev He^3 particles from the NRL 2-Mv Van de Graaff accelerator. The gammas from the decay of these states were measured with the aid of a 20-channel analyzer and a 1-in. diameter×1½ in. long NaI(Tl) crystal having 6% resolution for 1-Mev gammas. Five gamma energies were observed with tentative values of 2.49, 2.10, 1.69, 1.06, and 0.94 Mev, and are assigned to states of the same energies respectively. Probably the 1.05-Mev level of Middleton and Tai[1] and the 1.075-Mev level of Price[2] are not the same as has been suggested, but instead the 1.05-Mev level and our 0.94-Mev level are the same and have $T=0$. Our 1.06-Mev level and Price's 1.075-Mev level are the same and probably have $T=1$ corresponding to the ground state of O^{18}. A possible set of parameters that are consistent with our data and the data of Price are as follows: 5.67-Mev level $0,1^-$ ($T=0, J=1, \pi=-$); 5.60-Mev level $0,1+$; 1.07-Mev level $1,0+$; 0.94-Mev level $0,3+$.

[1] R. Middleton and C. T. Tai, Proc. Phys. Soc. (London) A, **64**, 801 (1951).
[2] P. C. Price, Proc. Phys. Soc. (London) A, **68**, 553 (1955).

GA6. Scattering of 19-Mev Alpha Particles by Neon.* Leo Seidlitz, E. Bleuler, and D. J. Tendam, *Purdue University.*—The angular distribution of 19-Mev alpha particles scattered by Ne has been measured in the range 10°–170° (laboratory). The detectors were nuclear emulsions mounted every 2½° in an 18-inch scattering chamber. The differentiation between alpha and proton tracks was improved by fading of the latent image and differential development. The maximum divergence of the incident beam was ±½°, that of the detected scattered particles was ±1°. The distribution of the elastically scattered alpha particles exhibits pronounced, regular oscillations, similar to those observed in Al. There are 8 minima in the above range, spaced approximately 20° apart. The maxima rise from 0.3 of the Rutherford cross section at 30° (c.m.) to 0.75 at 160°. The largest ratio between successive maximum and minimum is 25. The inelastic groups corresponding to the excitation of the 1.63-, 4.36-, and the 5.4-Mev levels in Ne^{20} and the 3.35- and 4.9-Mev levels in Ne^{22} were resolved and partial angular distributions measured. The first three oscillations of the 1.63-Mev group are out of phase with those of the elastic group. Tentative results for the scattering by argon will also be presented.

* Work supported by the U. S. Atomic Energy Commission.

GA7. Angular Distributions of Protons Inelastically Scattered from Ne^{20}. G. Schrank and G. K. O'Neill, *Princeton University.*—Protons inelastically scattered from neon-20 have been observed at 12 angles. 18-Mev protons entered a 60-inch diameter scattering chamber filled with natural neon gas at 2 cm pressure. The scattering volume was defined by a standard slit system of 3.5 degrees angular aperture in front of the NaI counter. With an energy resolution of 2.3% in the scintillation spectrometer, eight proton groups were resolved. These correspond closely to previously determined levels at 1.63, 4.26, 4.97, 5.81, 7.45, 7.85, 9.2, and 10.0 Mev.[1,2] Of the five levels at 6.74(0+), 7.18(3−), 7.22(0+), 7.45(2+), and 7.85(2+), only the last two appeared with measurable intensity in this experiment. None higher than 10 Mev were resolvable. The first level, at 1.63 Mev, exhibits a forward peak, a minimum at 65 degrees, and some additional structure at backward angles. This distribution is in sharp contrast to results for 10-Mev protons, which show symmetry about 90 degrees.[3] Graphs of the absolute differential cross sections for the observed eight levels will be shown, and will be compared with the rough descriptions now available.

[1] A. Sperduto and W. W. Buechner, M. I. T. Annual Progress Report No. 38.
[2] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **27**, 77 (1955).
[3] Freemantle, Prowse, Hossain, and Rotblat, Phys. Rev. **96**, 1270 (1954).

GA8. Low-Lying Levels in Mg^{25} from the Reaction $Mg^{25}(p,p'\gamma)Mg^{25}$, and from Na^{25} Beta Decay. H. E. Gove, A. E. Litherland, E. B. Paul, and G. A. Bartholomew, *Chalk River Laboratories.*—Further[1] measurements on this reaction give the branching ratios of the 1.61- and 1.96-Mev levels in Mg^{25}. The former decays directly to ground (>95%), while the latter decays to ground or to the levels at 0.58 or 0.98 Mev in the proportions 30:55:15. Gamma rays following beta decay of Na^{25} show that the levels in Mg^{25} at 0.98 and 1.61 Mev are fed. Gamma rays from beta transitions to the 0.58 level are less than 3% of the total. This is in disagreement with previous work[2] in which they were found to be about 10%. Assuming that the 0.98 Mev level is the mirror of the 3/2+ level[3] at 0.95 Mev in Al^{25}, this indicates $J=5/2+$ for Na^{25}. The 1.61-Mev level then has $J\leq 7/2+$. Comparisons between the branching ratios of levels in Mg^{25} and those in Al^{25} show similarities and indicate that the 1.96-Mev level is the mirror of the 5/2+ level at 1.81 Mev[3] in Al^{25}.

[1] H. E. Gove *et al.*, Phys. Rev. **99**, 1649(A) (1955).
[2] D. Maeder and P. Staehelin, Helv. Phys. Acta **28**, 193 (1955).
[3] Litherland, Paul, Bartholomew, and Gove (to be published).

GA9. Distribution of Protons from $Al^{27}(n,p)Mg^{27}$.* R. K. Haling, *Brown University.*—A study has been made of the protons emitted by an aluminum foil target when bombarded by 14-Mev neutrons. The neutrons are produced by the $T(d,n)He$ reaction using 175-kev deuterons from the Brown University Cockcroft-Walton accelerator. Emitted protons are analyzed by means of 400μ Ilford C2 emulsion plates placed at angles of 30°, 60°, 90°, 120°, and 150° with respect to the incident neutron beam. Clearly resolved groups are observed corresponding to Mg^{27} excitation energies of 1 Mev and 3.5 Mev, with some indication of levels at 5.7 Mev and 6.9 Mev. In approximately 10% of the observations the residual nucleus was left in the 3.5-Mev level, while 1% corresponded to the 1-Mev level. Reactions resulting in the ground state of Mg^{27} accounted for less than 0.2% of the emitted protons. The angular distribution shows greatest intensity in the forward direction, both for the 3.5-Mev level and for the total yield. The cross section for this reaction (for protons emitted with $E_p>2$ Mev) is estimated at 18±5 mb.

* Supported in part by the U. S. Atomic Energy Commission.

GA10. Rotational Levels in Al^{25}. A. E. Litherland, E. B. Paul, G. A. Bartholomew, and H. E. Gove, *Chalk River Laboratories.*—The gamma cascading below 4-Mev excitation in the nucleus Al^{25} can be described in terms of transitions between the members of four overlapping rotational bands.[1] Three of the bands based on excited states of Al^{25}, including the negative parity band, require the assignment of the quantum number $K=1/2$.[1] Each of these three bands has three observed members, including $J=1/2$, and the level spacing associated with $K=1/2$.[1] The assignment is also supported by the inhibited nature of the dipole transitions to the ground-state band to which is assigned $K=5/2$. The moments of inertia obtained from the $K=1/2$ bands are greater than the value calculated from the first two excited states of Mg^{24}. The ground-state band, however, has a smaller moment of inertia.

[1] *Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn, Chapter XVII, by A. Bohr and B. Mottelson.

GA11. Upper Limits to the Lifetimes of Excited States in Al^{27} and Na^{22}.* C. P. Swann and W. C. Porter, *Bartol Research Foundation.*—The recoil technique described by

Devons *et al.*[1] has been applied to the 440-kev level of Na^{23}, the 840-kev and 1010-kev levels of Al^{27}, and the 108-kev level of F^{19}. In all cases the excited nuclei were produced by inelastic proton scattering. The result obtained for the F^{19} level agrees with previously reported work.[2] For the other states only upper limits could be established. The mean lives of the two levels in Al^{27} are shorter than 10^{-10} sec whereas that for the level in Na^{23} is shorter than 2.5×10^{-11} sec. From the cross section for the Coulomb excitation[3] of the 440-kev level of Na^{23} the partial $E2$ mean life can be calculated provided the spin of the excited state is known. The shortest value estimated in this way (for spin $\frac{1}{2}$) is 6×10^{-11} sec. A combination with our upper limit shows that the 440-kev radiation must be a mixture of $M1$ and $E2$ with the $M1$ at least as strong as the $E2$.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Devons, Hereward, and Lindsey, Nature **164**, 586 (1949).
[2] Thirion, Barnes, and Lauritsen, Phys. Rev. **94**, 1076 (1954).
[3] G. M. Temmer and N. P. Heydenburg, Phys. Rev. **94**, 426 (1954).

GA12. Low Levels of Si^{29} from the $Si^{29}(pp'\gamma)Si^{29}$ Reaction and from the Beta Decay of Al^{29}. D. A. BROMLEY, H. E. GOVE, A. E. LITHERLAND, E. B. PAUL, AND E. ALMQVIST, *Chalk River Laboratories.*—A measurement of the yield curve for the $Si^{29}(pp'\gamma)Si^{29}$ reaction using a Si^{29} enriched target has located 10 resonances in the proton energy range 2.5 to 3.0 Mev. The 2.03-Mev level in Si^{29} has previously been found to be $3/2+$ or $5/2+$.[1] Angular distributions of the 2.03-Mev gamma radiation at a few of the resonances have established that this level is $5/2+$. Coincidence measurements have shown that the cascade through the 1.28-Mev level occurs in only about one percent of the transitions from the 2.03 level, the remainder going by $E2$ radiation directly to the ground state. To investigate these levels further, Al^{29} has been produced by the $Si^{29}(n,p)Al^{29}$ reaction with 14-Mev neutrons. A study of the gamma radiation following the Al^{29} beta decay indicates that the number of beta transitions to the 1.28-Mev and to the 2.43-Mev levels is in the ratio of 15.2 ± 1.5 to 1. This is over a factor of two higher than has previously been reported.[2] No evidence has been found either for a beta-decay branch to the 2.03-Mev level or for cascade de-excitation of the 2.43-Mev level through that at 1.28 Mev.

[1] J. R. Holt and T. N. Marsham, Phys. Rev. **89**, 665(L) (1953).
[2] Roderick, Lönsjö, and Meyerhof, Phys. Rev. **90**, 371(A) (1953).

TUESDAY MORNING AT 9:30

Terrace Room

(C. S. WU presiding)

Invited Paper

H1. Experiments Relating to the Long Life of Carbon-14. RUBBY SHERR, *Princeton University.* (30 min.)

Radioactive Nuclei, I

H2. Decay of S^{37}.* H. MORINAGA AND E. BLEULER, *Purdue University.*—According to early absorption measurements,[1,2] the decay of S^{37} is characterized by a first forbidden transition to the ground state of Cl^{37} and a fast transition ($\log ft=4.2$) to an excited state at about 2.7 Mev which decays directly to the ground state. Since, in these experiments, weak beta or gamma transitions to lower excited states would not have been detected, a careful reinvestigation of the gamma-ray spectrum of S^{37} was undertaken using a NaI spectrometer. Only one strong gamma ray of 3.1 Mev was found, the upper limit for the relative intensity of any other gamma ray below 2 Mev being 1%. Preliminary beta-ray measurements with a Plastifluor scintillator confirmed the previous values for the end point of the low-energy component (1.6 Mev) and the branching ratio (~90%). The results appear to indicate a scarcity of low-lying states of Cl^{37}, which is compatible with the model proposed by King,[3] as is the existence of the fast transition to the 3.1-Mev state.

* Work supported by the U. S. Atomic Energy Commission.
[1] D. J. Hughes *et al.*, Plutonium Project Report, CP-3647 (unpublished).
[2] E. Bleuler and W. Zünti, Helv. Phys. Acta **19**, 137 (1946).
[3] R. W. King, to be reported at this meeting.

H3. Decay of A^{35}.* O. C. KISTNER, A. SCHWARZSCHILD, AND B. M. RUSTAD, *Columbia University and Brookhaven National Laboratory.*—The mirror transition, $A^{35}(\beta^+)Cl^{35}$, has been studied with magnetic lens beta-ray and NaI scintillation spectrometers. This decay is of particular interest because its properties are favorable for electron-neutrino angular correlation experiments. Argon-35 was produced by bombarding liquid CCl_4 with 10 Mev protons from the Brookhaven cyclotron. The gas was purified with liquid nitrogen and hot calcium traps. The logarithmic decay curve is linear with a half-life of 1.83 ± 0.02 seconds, in agreement with previous measurements.[1] The Kurie plot of the beta spectrum has an end point of 4.95 ± 0.04 Mev which is quite different from the previous determination of 4.41 Mev by cloud chamber method.[1] This maximum energy is also in excellent agreement with the value[2] predicted from the consideration of Coulomb energy. A slight deviation from the linear Kurie plot not attributable to scattering indicates possible weak lower groups. Two gamma rays amounting to not more than a few percent of the total activity were observed at 1.19 ± 0.04 and 1.73 ± 0.04 Mev. These energies agree reasonably with reported levels in Cl^{35}.[3] The ft value of A^{35} is 5800 sec with an estimated error of 10%.

* This work was partially supported by the U. S. Atomic Energy Commission.
[1] P. M. Endt and J. C. Kluyver, Revs. Modern Phys. **26**, 95 (1954).
[2] D. C. Peaslee, Phys. Rev. **95**, 717 (1954).
[3] Pieper, Stanford, and von Herrmann, Phys. Rev. **98**, 1185 (1955).

H4. Disintegration of A^{41}.* A. SCHWARZSCHILD, B. M. RUSTAD, AND C. S. WU, *Columbia University and Brookhaven National Laboratory.*—Argon-41 decays by emissions of two β groups and one γ ray. Thin lens and semicircular magnetic spectrometers were both used to investigate the β spectra. The published maximum energy of the intense low-energy spectrum has been found to be in error. The low-energy spectrum has an allowed shape from 0.150 Mev to the end point at 1.199 ± 0.008 Mev. The high-energy spectrum has an unique first forbidden shape ($\Delta J=2$, yes) confirming a spin and parity assignment of $7/2^-$ for A^{41} as predicated by the shell model. The maximum energy of this group is 2.48 ± 0.04 Mev and the intensity is 0.88% of total disintegrations. This yields

the $\log f_1 t$ value of 8.50 which agrees well with $\log f_1 t$ values of other known unique first-forbidden transitions. The γ-ray energy is 1.290 ± 0.005 Mev as measured with a NaI scintillation spectrometer calibrated with the Na^{22} and Co^{60} γ rays. The $A^{41} - K^{41}$ mass difference, which has not been measured by other means, is thus 2.489 ± 0.010 Mev. A method of determining the "background" in the region of the weak high energy due to the intense low energy β and the γ ray will be discussed.

* This work was partially supported by the U. S. Atomic Energy Commission.

H5. Decay of K^{40}. L. T. ALDRICH, G. W. WETHERILL, G. L. DAVIS, AND G. R. TILTON, *Carnegie Institution of Washington.*—The decay of K^{40} to A^{40} by electron capture has been studied by comparing ratios of A^{40}/K^{40}, Pb^{206}/U^{238}, and Pb^{207}/U^{235} obtained from minerals from the same rock. This problem was first attempted in this way in a quantitative manner by Wasserburg and Hayden[1] who compared the ratio A/K in feldspar to the Pb/U ratios in uraninite from the same pegmatite. It has subsequently been shown in this laboratory[2] that micas invariably contain as much or more radiogenic argon per gram of potassium than do feldspars in the same rock. Micas and uraninites from six pegmatites varying in age from 400 to 2600 million years have been analyzed.

The decay constant for electron capture λ_e may be determined most sensitively from the younger rocks. Having λ_e, one may place limits on the value for λ_β by examining the data for old rocks. The data are consistent with $a\lambda_e = 3.2$ dpm/gram K and a ratio λ_e/λ_β of 0.116. These values lie well within the range of values for these decay constants as found by laboratory experiments.[3]

[1] G. J. Wasserburg and R. J. Hayden, Geochim. et Cosmochim. Acta **7**, 51 (1955).
[2] Wetherill, Aldrich, and Davis, Geochim. et Cosmochim. Acta **8**, 171 (1955).
[3] P. M. Endt and J. C. Kluyver, Revs. Modern Phys. **26**, 95 (1954).

H6. Half-life of Rb^{87}.—G. W. WETHERILL, L. T. ALDRICH, G. R. TILTON, AND G. L. DAVIS, *Carnegie Institution of Washington.*—The concentration of Rb^{87} and radiogenic Sr^{87} in samples of both feldspar and mica have been determined by the mass spectrometric isotope dilution technique. Pb^{206}/U^{238} and Pb^{207}/U^{235} ages of uranium minerals from the same rock bodies have been measured. The two uranium ages agree within 2%.

Sample	Mineral	Sr^{87}/Rb^{87}	Uranium age
Bikita, S. Rhodesia	lepidolite	0.0369	2680 m.y.
Viking Lake, Sask.	biotite-chlorite	0.0264	1890
Keystone, S. Dakota	lepidolite	0.0236	1600
	microcline	0.0224	1600
	muscovite	0.0244	1600
Cardiff Twp., Ontario	muscovite	0.0138	1020
Wilberforce, Ontario	biotite	0.0137	1030
Spruce Pine, N. C.	muscovite	0.00500	375
	microcline	0.00535	375

The calculated average value of $t_{\frac{1}{2}}$, $5.0 \pm .2 \times 10^{10}$ yr, is lower than most of the published values which average about 6.1×10^{10} yr, but it is higher than a recent counting measurement (4.3×10^{10} yr).[1]

[1] I. Geese-Bähnisch and E. Huster, Naturwiss. **41**, 495 (1954).

H7. Lower Limits for the Half-Lives of Ca^{48} and Zr^{96}, against Double Beta Decay.* MIGUEL AWSCHALOM,† *University of Rochester.*—Using two scintillation counters in a 4π solid angle geometry, a search for double beta decay in Ca^{48} and Zr^{96}, was carried out deep underground. The counting rates in the spectral region of interest were very low, and no evidence was found for the existence of double beta decay in either of these isotopes. The half-lives of Ca^{48} and Zr^{96}, against double beta decay were estimated to be larger than 2×10^{15} yr, and 0.5×10^{18} yr, respectively. These half-lives are longer than those that can be predicted using Majorana type neutrinos and reasonable matrix elements.[1] The conclusion is that the neutrino and antineutrino are nonidentical particles.

* Work performed under contract with the U. S. Atomic Energy Commission.
† Present address: Louisiana State University.
[1] H. Primakoff, Phys. Rev. **85**, 888 (1952); and private communication September 12, 1955.

H8. Gamma Radiation from Co^{56}. C. SHARP COOK AND F. M. TOMNOVEC, *U. S. Naval Radiological Defense Laboratory.*—The gamma radiation from Co^{56} has been studied using a 4-in. diameter by 4-in. high cylindrically-shaped NaI(Tl) crystal, a DuMont type 6364 photomultiplier tube, and a 20-channel pulse-height analyzer capable of being expanded to give 100 channels in a single spectrum. The relative intensities of the gamma radiation from Co^{56} have been found to be: 0.511-Mev annihilation radiation, 0.267; 0.845-Mev, 1.000; 1.20-Mev, 0.675; 1.71-Mev, 0.176; 2.00-Mev, 0.128; 2.55-Mev, 0.196; and 3.25-Mev 0.128.

TUESDAY MORNING AT 9:30

Panel Room

(A. S. NOWICK presiding)

Solid-State Physics: Nonmetals

HA1. Energy of Cohesion, Compressibility, and Potential Energy Functions of the Graphite System. L. A. GIRIFALCO AND R. A. LAD, *Lewis Flight Propulsion Laboratory.*—The lattice summations of the potential energy of importance in the graphite system have been computed by direct summation assuming a Lennard-Jones 6–12 potential between carbon atoms. From these summations, potential energy curves were constructed for interactions between a carbon atom and a graphite monolayer, between a carbon atom and a graphite surface, between a graphite monolayer and a semi-infinite graphite crystal, and between two graphite semi-infinite crystals. Using these curves, the equilibrium distance between two isolated physically interacting carbon atoms was found to be 2.70 a, where a is the carbon-carbon distance in a graphite sheet. The distance between a surface plane and the rest of the crystal was found to be 1.7% greater than the interlayer spacing. Theoretical values of the energy of cohesion and the compressibility were calculated from the potential curve for the interaction between two semi-infinite crystals. They were $\Delta E_c = -330$ erg/cm² and $\beta = 3.18 \times 10^{-12}$ cm²/dyne, respectively. These compared favorably with the experimental values of $\Delta E_c = -260$ erg/cm² and $\beta = 2.97 \times 10^{-2}$ cm²/dyne.

HA2. Effect of Neutron Irradiation on the Low-Temperature Specific Heat of Graphite.* W. DESORBO AND W. W. TYLER, *General Electric Research Laboratory.*—The specific heat of

highly irradiated graphite has been measured from 16° to 300°K. In the temperature range 16° to 55°K the specific heat deviates from a T^2 dependence previously reported for the unirradiated specimen.[1] Stored energy content of the irradiated material is about 475 cal/g. The specific heat of the irradiated graphite is larger than that of the unirradiated sample throughout the entire temperature range studied. This difference in C_p is explained by the assumption that interplanar atoms in the irradiated material contribute to the specific heat like low-frequency Einstein oscillators. On this assumption a rough value may be deduced for the number of interplanar atoms. The derived thermodynamic functions are compared with those previously obtained for the unirradiated graphite and also with those of a "single crystalline" foliated natural graphite.[2] The entropy of the irradiated sample at 298.16°K is 1.492±0.009 cal/g-atom deg of which 0.015 is approximated from 16° to 0°K assuming the third law.

* Work supported by the U. S. Atomic Energy Commission under Contract No. W-31-109-Eng-52.

[1] W. DeSorbo and W. W. Tyler, J. Chem. Phys. **21**, 1660 (1953).
[2] W. DeSorbo, J. Am. Chem. Soc. **77**, 4713 (1955).

HA3. Some Effects of Reactor Irradiation on the Infrared Spectrum of Polyethylene. F. R. CROWNFIELD, JR., J. F. DINWIDDIE, AND F. W. LANCASTER, *North Carolina State College.*—Studies of the effects of nuclear radiations on the infrared spectrum of a material may be of importance for several reasons. These include the improvement of our understanding of the structure of the material itself and the furthering of our understanding of the mechanisms of the radiation damage to materials. Samples of polyethylene were irradiated in the Raleigh research reactor and in the Brookhaven reactor. The infrared spectra of these samples were compared to those of similar but unirradiated samples. We have observed changes in the infrared spectrum corresponding to oxidation of the samples, to the production of unsaturated bonds, and to basic changes in the structure which may be associated with cross linking of the polymer chains. The structure of samples irradiated for a total thermal neutron exposure of 10^{18} neutrons/cm² resembles that of glass. Comparison of samples receiving total exposures of the order of 10^{15} neutrons/cm² (thermal) in the Raleigh reactor and in the Brookhaven reactor gave quite different results, which may be partly explained on the basis of differences in the relative amounts of fast neutron, thermal neutron, and gamma-ray exposure. Results of measurements of the infrared spectra run at elevated temperatures in order to separate the effects due to crystallinity of the sample from those due to cross linking will be presented.

HA4. Annealing of Some Irradiation Effects in NaCl Irradiated with High-Energy Protons. KOICHI KOBAYASHI, *Carnegie Institute of Technology.*—Sodium chloride crystals were subjected to irradiation at room temperature by 350-Mev protons with a total flux of 10^{12} to 10^{16} protons per cm². Changes in their electrical conductivity, stored energy, and optical absorption were studied during warmup at a rate of 2°C/min. These showed maxima around 150°C and 250°C and annealed out at about 400°C. The results of the stored energy measurements indicate the presence of three stages of annealing, the first lies between room temperature and 150°C, the second between 150°C and 250°C, and the third is above 250°C. The stored energy curve has maxima at 100°C, 200°C, and 310°C. The absorption spectrum has been found to change considerably in the second stage. Efficiency of the production of defects was estimated to be of the order of 10^3 per proton per centimeter path, and this is compared with theories of Seitz and of Smoluchowski.

HA5. Lattice Distortion and X-Ray Diffraction Intensities in Crystals Containing Localized Defects. WILLIAM J. TAYLOR, *The Ohio State University.*—Assume a defect at $\mathbf{r}_\alpha$ displaces a lattice atom at $\mathbf{r}_j$ by a vector $\mathbf{u}_{j\alpha}$ depending only on $\mathbf{r}_j-\mathbf{r}_\alpha$, and that total displacement of the jth atom is $\mathbf{u}_j=\Sigma_\alpha\mathbf{u}_{j\alpha}$, summed over all *defects*. Lattice expansion is represented by mean displacement for all defect configurations, $\langle\mathbf{u}_j\rangle=z\Sigma_\alpha\mathbf{u}_{j\alpha}$, where the sum is over all defect *sites*, and z is the fraction of sites occupied.[1,2] Let $\mathbf{u}_j'=\mathbf{u}_j-\langle\mathbf{u}_j\rangle$ be the displacement from the mean position. Diffraction intensities depend on mean values $\langle\exp(i\mathbf{k}\cdot\mathbf{u}')\rangle$, where $\mathbf{k}/2\pi$ is change in wave vector, and $\mathbf{u}'=\mathbf{u}_j'$ and $\mathbf{u}_j'-\mathbf{u}_k'$ for Laue-Bragg and diffuse scattering, respectively. Assume that only *one* defect is permitted at a site, but that distribution is otherwise random. Then an exact calculation yields: $\langle\exp(i\mathbf{k}\cdot\mathbf{u}')\rangle=\mathbf{\Pi}_\alpha[1-2z(1-z)(1-\cos\mathbf{k}\cdot\mathbf{u}_\alpha)]$, where $\mathbf{u}_\alpha=\mathbf{u}_{j\alpha}$ or $\mathbf{u}_{j\alpha}-\mathbf{u}_{k\alpha}$, and the convergent product extends over all defect sites. For $z\to0$ this approaches a previous result in which no limitation was put on number of defects at a site.[3] Both calculations are more general than that of Huang[1] in that no special form of displacement $\mathbf{u}_{j\alpha}$ is assumed, and the mean values of the exponentials are computed exactly, whereas Huang expanded the latter and discarded higher order terms.

[1] K. Huang, Proc. Roy. Soc. (London) **A190**, 102 (1947).
[2] J. D. Eshelby, J. Appl. Phys. **25**, 255 (1954).
[3] W. J. Taylor, Phys. Rev. **95**, 666 (1954).

HA6. Vacancies and Replacements in a Solid Resulting from Heavy Corpuscular Radiation. W. S. SNYDER, *University of Tennessee and Oak Ridge National Laboratory,* AND J. NEUFELD, *Oak Ridge National Laboratory.*—Let $D(E)$ be the number of atoms displaced in a monoatomic solid due to a free atom of energy E, and let $V(E)$ be the number of vacancies produced by the same atom. When a struck atom has received energy y, $p(y)$ denotes the probability it is displaced, and if displacement has occurred, the probability that the striking atom replaces it, is taken as $q(E-y)$. Assume a minimum amount of energy y_0 is necessary to displace an atom and that the struck atom loses this amount of energy in breaking away from its lattice site. Taking y_0 as the unit of energy, $p(x)=D(x)=V(x)=0$ for $x<1$. If $K(E,y)$ is the scattering kernel, then D and V are solutions of the equation,

$$f(e)=\int_0^E dyK(E,y)\{p(y)[f(y-1)+1-\theta q(E-y)]+(1-p(E-y)q(y))f(y)\},$$

with $\theta=0$ for displacements and $\theta=1$ for vacancies. This equation is solved for some representative cases of $p(y)$ and $q(y)$ and the results are compared with experiments.

HA7. Application of the Theory of Absolute Reaction Rates to the Creep Failure of Polymeric Filaments. BERNARD D. COLEMAN, *E. I. duPont de Nemours and Company.*—A discussion is given of the creep failure of partially oriented polymeric filaments. The theory of absolute reaction rates is used to obtain differential equations which permit the calculation of the lifetime of a single filament when it is subjected to different uniaxial loading histories. Explicit expressions are obtained for the lifetime of a filament for three special cases: dead loads, loads increasing linearly with time, and sinusoidal loads. Results of lifetime under dead-load measurements are presented for drawn 66 nylon yarns. The treatment of the data by the theory yields plausible values for the molecular parameters involved. It is shown that the parameters which are calculated from the dead-loading experiments may be used to calculate the dependence of the tensile strength on the speed of measurement (when obtained using a constant rate of loading tester). Tensile strength values were measured at rates of loading in the range between 0.14×10^9 and 4.8×10^9 dynes cm^{-2} sec^{-1} and found to be in satisfactory agreement with those predicted by the theory.

HA8. Low-Temperature Structure of Vitreous Silica. M. DANK AND S. W. BARBER, *Owens-Illinois Glass Company.*—Vitreous silica has long been considered from x-ray studies[1] and the macroscopic isotropy of various physical properties to be a random continuous silicon-oxygen network with close-range order no greater than about 8 A. Light scattering,[2] electron microscope,[3] and low-angle x-ray[4] experiments have cast doubt as to the validity of this structural interpretation. Recent low-temperature heat capacity measurements[5] on vitreous silica and cristobalite have been fitted between 5° and 30°K by a modified form of the Tarassov[6] function and suggest the existence at low temperatures of highly anisotropic domains in vitreous silica. The heat capacity data for quartz and binary alkali silicate glasses will be discussed.

[1] B. E. Warren and J. Biscoe, J. Am. Ceram. Soc. **21**, 49 (1938).
[2] P. Debye and A. M. Bueche, J. Appl. Phys. **20**, 518 (1949).
[3] A. F. Prebus and J. W. Michener, Ind. Eng. Chem. **46**, 147 (1954).
[4] L. C. Hoffman and W. O. Statton, Nature **176**, 561 (1955).
[5] E. F. Westrum, Jr., (to be published).
[6] V. V. Tarassov, Zhur. Fiz. Khim. **XXIV**, III (1950).

HA9. On the Calculation of the Band Structure of Polyatomic Crystals. B. SEGALL, *General Electric Research Laboratory.*—The method for the calculation of the band structure of crystals with one atom per unit cell developed independently and along different lines by Korringa and Kohn and Rostoker has been generalized to include polyatomic crystals (those having several atoms per unit cell). In this method the crystal potential is approximated by a potential which is spherically symmetric inside nonoverlapping spheres about all the atomic sites and is constant elsewhere. The secular equation yielding the required E *vs* $\mathbf{k}$ relationship and equations determining the wave functions that have been derived have the same form as those for the monatomic case. In the generalized equations there appear besides the "structure constants" of a monatomic crystal other constants whose significance and evaluation will be discussed. While having the advantages of the cellular method, the present method avoids the difficulties associated with satisfying boundary conditions. Other virtues of the method are that the greatest part of the labor involved is in the calculation of the potential independent "structure constants" and that the method promises to be rapidly convergent. The applicability of the method and a computational program for the study of certain diatomic crystals will be discussed.

HA10. Multiplet Structure of Excitons in Ionic Crystals.* A. W. OVERHAUSER, *Cornell University.*—The excited states of crystals arising from the configuration in which an electron is transferred from a negative ion to a nearest neighbor positive ion are analyzed. It is concluded that 72 overlapping exciton bands result for crystals having the NaCl structure. Optical transitions from the ground state are allowed to only 5 of the 30 energy levels into which the 72 bands collapse at the center of the Brillouin zone. For crystals having the CsCl structure 96 bands occur which collapse into 40 energy levels at $k=0$, 6 of which can be reached from the ground state by allowed optical dipole transitions. In the absence of spin-orbit interaction only two transitions are allowed for both structures. It is concluded that the lifetime of exciton states, as limited by interaction with optical phonons, is sufficiently short to account for the width and temperature dependence of fundamental absorption lines. Approximate wave functions describing the exciton states are constructed, and a procedure for calculating energy levels and relative intensities of absorption components is formulated.

* Supported in part by the Office of Naval Research.

HA11. Color Centers in Potassium Iodide Crystals Containing Excess Iodine. GORDON A. NOBLE AND LEONARD BRONSTEIN, *Zenith Radio Corporation.*—We have studied the effect of heat treatment on the hole bands in potassium iodide crystals. Previous absorption spectra reported by Mollow, Uchida, Nakai, Maurer, and Houston differ in details.[1] If the crystals are cooled slowly they show a broad absorption in the blue region which is probably due to colloidal iodine. If the crystal is heated and rapidly quenched the spectrum shows absorption peaks at 4.67 ev, 3.49 ev, and a poorly resolved peak at about 4.16. The relative intensities of the bands which form in the crystal are primarily determined by the temperature to which the crystals are haeted, time at maximum temperature, and the rapidity of quenching. The band at 4.7 ev is the most stable at higher temperatures and the band at 3.5 ev is primarily formed at 450°C. The samples used in these measurements were about a millimeter thick and were quenched in carbon tetrachloride. The relation between these absorption bands and the models suggested for V-centers will be discussed.

[1] E. Mollow, Ann. Physik **29**, 394 (1937); Y. Uchida and Y. Nakai, J. Phys. Soc. (Japan) **9**, 928 (1954); B. Houston, unpublished thesis, University of Illinois (August, 1955).

HA12. Ionic Densities and Mobilities from Polarization Data.* W. E. DANFORTH AND J. F. MARSHALL, *Bartol Research Foundation.*—Studies are being made to determine number and mobilities of ions in an ionic conductor by theoretical interpretation of the initial slope of the polarization curve. The experimental data to be described are obtained by applying a constant voltage to a crystal of thorium oxide at elevated temperatures *in vacuo*. At the instant the voltage is applied the current rises to a definite value and subsequently decays as the polarization emf develops. The primary datum for the present purpose is the initial slope of the current decay. An unpublished theoretical development by J. F. Marshall shows that, if it can be assumed that only one kind of carrier is present, the density of carriers can be calculated from the initial slope of the polarization curves. Conductivity values are obtained from the initial rise of current at the instant of application of voltage and therefore mobilities also may be calculated. Reasonable values of ionic densities and mobilities are found for temperatures below 1000°C; at higher temperatures the theory is less satisfactory due perhaps to increasing density of free electrons.

* Supported in part by U. S. Army, Office of Ordnance Research.

HA13. Electrical Conductivity of BaO Single Crystals as a Function of Temperature and Excess Barium Density.* R. T. DOLLOFF,† *Cornell University.*—Electrical conductivities of crystals containing excess barium densities between 3×10^{16}/cc and 6×10^{17}/cc have been measured for the temperature range from 500 to 900°K. The barium was introduced by heating the crystals in a barium atmosphere, and the excess barium density was computed by the Smakula formula from the 2.0-ev absorption band following the method of Sproull, Bever, and Libowitz.[1] The conductivities are of the order of 10^{-7} mho/cm at 500°K and rise to values of about 1 mho/cm at 900°K with slopes of about 2.1 ev on a log conductivity *versus* T^{-1} plot. Conductivity maxima are observed at the high temperatures. If one assumes an electron mobility[2] of 5 cm/sec per v/cm, the electron densities at maximum conductivity agree with the optically determined excess barium densities to within a factor of three.

* Part of a dissertation submitted to Cornell University (November, 1955).
† Now at National Carbon Research Laboratories, Cleveland 1, Ohio.
[1] Sproull, Bever, and Libowitz, Phys. Rev. **92**, 77 (1953).
[2] E. M. Pell, Phys. Rev. **87**, 457 (1952).

TUESDAY MORNING AT 9:30

Empire Room

(J. KAPLAN presiding)

General Physics; Atmospheric Physics

I1. Conditions for Producing Nucleate Boiling, Film Formation, and Burnout Caused by Impulse Heating of Small Wires Immersed in Water. V. E. SCHERRER, C. FANEUFF, AND E. A. MCLEAN, *Naval Research Laboratory.*—Small diameter wires (1–15 mils) immersed in water at atmospheric pressure, were heated by 1 microsecond duration repetitive square pulses. Microscopic pictures were taken at 5000 frames per second using a stroboscopic light source. A phase diagram showing bands of nucleate boiling and film formation is obtained by plotting pulse energy *vs* bulk water temperature and connecting points representing the incidence of nucleate boiling, film formation, and burnout. The probability of producing nucleate boiling with 3-mil tungsten wire decreases approximately to zero, when the bulk water temperature is reduced to 140°F.

I2. Nucleate Boiling Caused by Impulse Heating. E. A. MCLEAN, C. FANEUFF, C. NANNEY, AND V. E. SCHERRER, *Naval Research Laboratory.*—Using the equipment and techniques described in the preceding paper, data was obtained on 15 mil Zircalloy and 3 mil tungsten wire over a range of values of energy per pulse and ambient water temperature. A discussion will be given of (1) the percentage of input energy utilized to form vapor as a function of water temperature and as a function of energy per pulse, and (2) the effect of wire diameter upon the incidence of nucleate boiling with pulse heating. Also, data will be shown of the most probable bubble diameter, bubble growth rates, bubble velocity away from the wire, number of bubbles per pulse, and the nucleation time for bubble formation.

I3. On Kinetic Friction between Dry Metallic Surfaces in Sliding Contact.* F. F. LING AND EDWARD SAIBEL, *Carnegie Institute of Technology.*—A theory of kinetic friction between dry metallic surfaces in sliding contact is proposed. It is found from a thermal and mechanical analysis under what conditions the Coulomb theory predominates, and under what conditions the weld-junction theory applies. Chemical reaction-rate theory is applied to find the coefficient of friction as a function of load, temperature, and velocity under the conditions for which the weld-junction process is operative.

* This work was supported in part by funds from a contract with the Office of Ordnance Research, U. S. Army.

I4. Sorption of Water by Wool. J. J. WINDLE, *Agricultural Research Service.*—A model for the system of wool plus sorbed water is proposed in which the sorbed water consists of three distinct molecular species: localized water irrotationally bound to localized sites in the fiber, mobile water with properties identical to bulk water, and intermediate water with a potential energy of sorption between that of the localized and mobile water. The theoretical isotherm for this system has been determined from statistical considerations and compared with the experimental isotherm for wool reduced to one hydrostatic pressure.[1] The statistical parameters of the model have been evaluated thereby and the distribution of the sorbed water among the three energy states inferred. Applications of this model to the interpretation of data on the microwave dielectric behavior of wool-water systems, on the heat of wetting of wool, and on the effects of sorbed water upon the elastic properties of the fiber will be discussed.

[1] A. B. D. Cassie, Trans. Faraday Soc. 41, 458 (1945).

I5. Implosion by Electrically Exploding Thin Metallic Foils. WILLIAM M. CONN.—The mechanism of electrically exploded wires was shown to include a phase in which a hollow cylinder of metallic vapor is formed; inside of the cylinder, spherical and cylindrical shocks are produced.[1] Replacement of the wire by a metallic thin foil which is electrically exploded at pressures from a few torr (mm Hg) to atmospheric pressure will be discussed. Foils of 0.0003 to 0.001 in. thickness were used in shapes: flat ribbon; open semicylinder; closed cylinder (axis of cylinder extending from electrode to electrode, 5 to 10 mm inside diameter). Luminosity, shocks, and metallic deposits on glass from the electrically exploded ribbon were similar to results of wires exploded under corresponding conditions. Semicylinders and cylinders showed implosion evidenced by very strong luminosity and cylindrical shocks. Metallic deposits were obtained for semicylinders on glass plates facing the outside of the metallic foil, whereas single "bullets" of metal were ejected with great force from the open side of the semicylinder. For x-ray flash exposures of electrically exploded short cylindrical foils of 22.5 mm diameter see Schall and Thomer.[2] Our patterns on glass slides showed similarity to characteristic patterns of wires.

[1] W. M. Conn, Phys. Rev. 98, 1551 (1955); Naturwiss. 42, 65 (1955); Z. angew. Phys. 7, 539 (1955).
[2] R. Schall and G. Thomer, Z. angew. Phys. 3, 41 (1951); G. Thomer, *ibid.* 5, 217 (1953).

I6. Diffraction Microscopy—a Light Microscope Method for the Measurement of Submicron Particles.* B. L. HENKE, *Pomona College* (introduced by C. A. Fowler, Jr.).—Submicroscopic particles can be detected by using the conventional dark-field illumination which consists of an intense hollow cone of radiation that converges from the substage condenser to a point on the sample and then spreads out with sufficient angle to "miss" the objective. By reducing the size of the aperture stop of the objective and the angular "thickness" of the illuminating cone, the radiation which forms a point image is characteristic of a particular angle of scattering from a particle. A method has been developed for varying this half-angle of the illuminating cone and for measuring the light flux which forms an image point. Information is thus obtained as to the angular distribution in the forward direction of energy which is scattered from a single particle. The deduction of particle size becomes relatively straightforward for the important class of problems involving a small difference between the refractive index of the particle and that of the surrounding medium—a condition which usually obtains for biological materials in solution, for example. The diffraction theory as applied in low angle x-ray diffraction techniques can be used for this case of "soft" scatterers in the 0.1 μ to 1 μ range.

* This work was supported by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command.

I7. Semiempirical Method for the Computation of Mass Absorption Coefficients for the Long Wavelength X-Ray Region.* R. WHITE AND B. L. HENKE, *Pomona College*

(introduced by C. A. Fowler, Jr.).—The measurement of absorption coefficients in the x-ray wavelength region of 5 to 50 A is usually very difficult because of the necessity for working in vacuum and for obtaining and measuring very small sample thicknesses. A considerable amount of work has been accomplished on the theoretical derivation of photoelectric absorption cross sections, but none of these results seems to constitute a practical basis for an extensive computation of mass absorption coefficients. Nevertheless wave-mechanical theory does suggest that a "universal" absorption equation should exist for this long wavelength region of the form $(\mu/\rho)(A/\lambda)=f_K(\lambda/\lambda_1)+f_L(\lambda/\lambda_2)\cdots$ in which (μ/ρ) is the mass absorption coefficient, A is the atomic weight, λ_1 and λ_2 are characteristic wavelengths which "measure" the binding of electrons in the K and L shells and which consequently depend on the atomic number of the element, and f_K and f_L are universal functions. An empirical method has been developed which has permitted the determination of these universal functions and the characteristic wavelengths from available absorption data. The "universal" functions have been expressed in both tabulated and equation form and do permit a rapid and precise computation of mass absorption coefficients for wavelengths in the 5 to 50 A region which lie below the critical L-absorption edge for the particular element.

* This work was supported by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command.

I8. Influence of Ozone on the Infrared Radiation in the Earth's Atmosphere. GILBERT N. PLASS,* *The Johns Hopkins University and Michigan State University.*—The upward and downward radiation flux and the heating and cooling rate in the atmosphere have been determined for the spectral region that is influenced by the 9.6 micron band of ozone. The radiation in this spectral band always acts to cool the atmosphere from the earth's surface to heights of several kilometers and to warm the region from there to approximately 20 km. The magnitude of the heating or cooling rates is never larger than a few tenths of a degree Centigrade per day in this region. On the other hand from 35 to 60 km the usual order of magnitude of the cooling rate is 2 to 3° C/day, but the cooling rate can be considerably larger than this if the upper layers have a higher temperature than normal. The effects of variations in the ozone concentration with height and of the temperature with height have been investigated separately. The calculations were made on an electronic computor from Summerfield's absorption measurements and take into account all physical phenomena known to be of importance in this problem, including Doppler and pressure broadening and the overlapping of the spectral lines.

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I9. Corona Point Discharge Currents Measured in Wind and Application to Thundercloud Theories. SEVILLE CHAPMAN AND ROY W. HENDRICK, JR., *Cornell Aeronautical Laboratory, Incorporated.*—Using corona point measurements from balloons, Simpson (1937) and ourselves (1948) calculated maximum thundercloud electric fields E as about 10^4 volts/meter, usually less. Conversely Gunn (1948) has numerous airplane measurements exceeding 10^6; Loeb (1954) believes average fields of 4×10^5 are needed for conduction maintenance of lightning leader strokes. In *still laboratory* air corona current i (amperes) varies approximately with $V(V-V_0)$, V being point potential. For an *isolated* point in *wind* we find conditions *entirely* different. Tests have been made in the Cornell Aeronautical Laboratory 8.5- ×12-foot throat trans-sonic wind-tunnel, on a point of radius 0.007 cm at static pressures P from 0.25 to 0.95 atmosphere, speeds v from 0 to 290 meters/second, and V from 0 to ±50 000 volts. Preliminary data reduction yields $i=1.4\times10^{-11}(P_0/P)^{0.5}v(V-V_0)$ where P_0 is one atmosphere and $V_0=6000\pm4000$ volts. For the balloon case on the new calibration theory $E=(2i/akl)^{0.5}$ where k=ionic mobility ($\sim4\times10^{-4}$ meter²/second volt), l=length of wire (meters) with points on either end; $a=1.4\times10^{-11}(P_0/P)^{0.5}$ farad/meter. Recalculating our maximum measured balloon current of 1.5×10^{-3} ampere gives $E=2.2\times10^5$ volts/meter, resolving the discrepancy.

I10. Plasma Oscillations and Radio Noise from the Disturbed Sun.* ROY W. GOULD,† *California Institute of Technology.*—In an attempt to understand the high intensity unpolarized bursts of radio noise reported by Wild *et al.*[1] two theoretical problems have been considered. The first is the growth of longitudinal plasma waves in an electron gas which has a bimodal velocity distribution. By considering energy transfer between electrons of different velocity it is shown that some of the waves which were previously interpreted as growing waves should be considered as evanescent waves. The conditions under which a continuous growth in wave amplitude can take place will be discussed. The second problem considered is the coupling between longitudinal and transverse waves in a medium whose electron density varies with position in a random manner. The rate of conversion of energy from plasma oscillations to transverse electromagnetic waves is evaluated in terms of the correlation distance and mean-square fluctuation in density. When thermal fluctuations are used in this expression the radiated electromagnetic energy is about 10^{-5} times the energy dissipated in short-range collisions, assuming typical coronal conditions.

* Work supported by the Office of Naval Research.
† Howard Hughes Fellow 1953–1955.
[1] Wild *et al.*, Aust. J. Phys. **7**, 439 (1954).

I11. Resonance Absorption in the Sodium Twilight Flash.* T. M. DONAHUE, ROBERT RESNICK, AND V. ROBERT STULL, *University of Pittsburgh.*—Interpretation of the measurements of scattered resonance radiation from the sodium layer in the upper atmosphere during twilight heretofore has been based on the implicit assumption that the incoming solar flux is unattenuated by the sodium layer itself on reaching the scattering region. This absorption is serious, however, for layer thicknesses in the range usually deduced.[1] A more exact treatment of the problem of calculating the density of atoms excited directly by sunlight, taking into account the line shape and reflections from the earth's surface but neglecting imprisonment, will be presented. As the layer thickness increases from 10^9 to 10^{11} atoms/cm² column, the number of atoms/cm² excited by the solar photons at first increases but then decreases due to the large attenuation. Despite the exponential decrease of density with altitude, the number of excited atoms can reach a maximum at the top of thick layers in early twilight. The resulting distribution provides the initial reservoir of excited atoms from which a final distribution may be obtained after imprisonment of re-emitted photons is considered.

* This work was supported in part by a grant from the National Science Foundation.
[1] T. M. Donahue and Robert Resnick, Phys. Rev. **98**, 1622 (1955).

I12. Diurnal and Seasonal Changes in the Natural Radioactivity of the Atmosphere. MARVIN WILKENING, *New Mexico Institute of Mining and Technology.*—Diurnal and seasonal changes in the natural radioactivity of the atmosphere have been studied using data obtained over a four-year period. A continuous monitor, which electrostatically precipitates particulate matter from the atmosphere onto a moving aluminum tape, was employed.[1] The well-known early morning maximum and late afternoon minimum in the diurnal course of natural radioactivity in the atmosphere can be attributed to vertical mixing, as evidenced by measurement of the "gust

amplitude" of surface winds. A marked seasonal fluctuation is observed, with a maximum occurring in October and a minimum during the spring months. These changes are shown also to be consistent with the vertical mixing hypothesis by correlation with mean surface-wind speeds.

[1] M. H. Wilkening, Nucleonics **10**, 36 (1952).

Invited Paper

I13. Electron Distribution in a New Model of the Ionosphere. H. K. KALLMANN, *University of California, Los Angeles.* (20 min.)

TUESDAY MORNING AT 9:30

Boston Room

(H. FESHBACH presiding)

Theoretical Physics, III

IA1. Cloudy Crystal Football or Pancake. EUGENE GUTH, *ORNL.*—We have developed an exact treatment of the scattering of neutrons on a cloudy crystal football or pancake. The chief analytical difficulty is in the averaging over the orientations of the nuclei. For energies >330 Mev Born approximation may be applied [also for scattering of electrons (Hofstadter *et al.*) on highly deformed nuclei, like Ta^{181}]; the averaging over orientations was carried out analytically for this case. For low energies the analytical apparatus (generalizing the Feshbah-Porter-Weisskopf treatment) was set up. Necessary machine calculations are planned and it is hoped to have a few results ready for the meeting. The experimentally lower (than cloudy crystal ball theoretically expected) maximum and the large spread of the observed maximum at $A\sim170$ was already qualitatively explained by Bohr and Mottelson as resulting from deviations from the ball shape. For a football or pancake one would expect results which roughly represent averages over the ball results taken over radii which lie between the smallest and the largest axis leading to a flattening of the maxima and a rise in the wings in the ball theoretical curves. A classification of the nucleonic states in deformed nuclei in the region $150<A<194$—where the equilibrium distortions are largest—has been given independently by Mottelson and Nilsson.

IA2. Charge Independence at 0.8 and 1.5 Bev.* M. M. BLOCK AND E. M. HARTH, *Duke University.*—Recent cloud-chamber data on $p-p$ scattering at 0.8 Bev[1] and 1.5 Bev[2] indicate that for single meson production, the ratio R of the reaction $p+p\rightarrow p+n+\pi^+(1)$ to $p+p\rightarrow p+p+\pi^\circ(2)$ is quite large. Application of charge independence to (1) and (2) shows that $R=1+2(|a_S|^2/|a_T|^2)$, where a_S and a_T are the amplitudes corresponding to the nucleons being coupled in an isospin singlet and triplet state, respectively. Since R is found to be large,[1,2] $|a_T|^2\ll|a_S|^2$. If we neglect a_T, it can be shown that charge independence requires that the proton and neutron in (1) have the same angular and momentum distributions, etc., i.e., the two nucleons have identical behavior. Experimental evidence will be presented in support of these conclusions. Extensions of these ideas to Fermi's theory[3] show that for the foregoing reaction there can be three values of R, namely, 1, ∞, or 3, the latter being the one chosen by Fermi.

* This work was supported by a joint Office of Naval Research and U. S. Atomic Energy contract.

[1] Fowler, Garrison, and Morris (private communication).
[2] Fowler, Shutt, Thorndike, and Whittemore (private communication).
[3] E. Fermi, Phys. Rev. **92**, 452 (1953).

IA3. Ratio of the Inelastic to Elastic Cross Section in p-p scattering.* F. R. WOODS AND J. A. LOCKWOOD, *University of New Hampshire.*—The correspondence method of Møller is used to derive the elastic and inelastic total cross section in $p-p$ scattering. In constructing the charge density, a retarded solution of the meson field equation is employed which, being velocity dependent, leads at appropriate energies to a complex potential field for the scatterer. The scattering is then considered as arising from a nucleon which may possess two energy states. The real component gives rise to elastic scattering while the imaginary components gives rise to the inelastic scattering. The ratio of the inelastic to elastic total cross section for scattering has been found and compared with the results reported[1] at the Fifth Annual Rochester Conference of January.

* Based on work supported by the Geophysical Research Directorate, Air Force Cambridge Research Center.

[1] *High Energy Nuclear Physics*, compiled by H. P. Noyes *et al.* (Interscience Publishers, Inc., 1955).

IA4. Determination of Proton-Proton Scattering Amplitudes. LINCOLN WOLFENSTEIN, *Carnegie Institute of Technology.*—Proton-proton scattering at any angle may be described in terms of five scattering amplitudes[1] B, C, G, N, and H. An attempt was made to determine these amplitudes at particular angles from recent double- and triple-scattering experiments[2] at 300 Mev without recourse to a phase-shift analysis. Extrapolating the data to 90° it is found that at least 15% and not more than 60% of 90° scattering is singlet, and that at least 35% and not more than 70% of 90° scattering is due to the C term, which corresponds to a simple spin-orbit coupling in the Born approximation. At least 2% and not more than 20% is due to the tensor-like H term. If we assume only 15% singlet scattering we find that the scattering amplitudes B and C are at right angles as in the Born approximation; if we assume the sign of the effective $\mathbf{L}\cdot\mathbf{S}$ potential to be the same as in the shell model, the scattering amplitude B must be negative such as that resulting from a repulsive potential. Discussion of the amplitudes near 0° will also be given.

[1] L. Wolfenstein, Phys. Rev. **96**, 1654 (1954).
[2] Ypsilantis *et al.*, Phys. Rev. **98**, 840 (1955).

IA5. Direct Interaction in Inelastic Neutron Scattering.* JOHN R. LAMARSH, *Brookhaven National Laboratory,* AND HERMAN FESHBACH, *M.I.T.*—The method of distorted waves has been used to calculate the angular distribution of the direct interaction contribution to the inelastic scattering of low-energy neutrons. At these energies the impulse approximation[1] is not valid. The interaction potential was taken to be a delta function, and the incident and emitted particles were assumed to move in a complex square well. Specific formulas

for the cross section have been derived, and these have been applied to the excitation of the first level in C^{12}. The angular distributions at 5.0, 5.5, and 6.0 Mev are strongly forward peaked. The effect of the complex part of the potential is to reduce the forward peak, an effect which increases with the energy of the incident particle.

* The part of the work done at Brookhaven National Laboratory was done under contract to the U. S. Atomic Energy Commission.
[1] Austern, Butler, and McManus, Phys. Rev. **92**, 350 (1953).

IA6. Nucleon Scattering and the Lomon-Feshbach Model.* ROBERT B. RAPHAEL, *Radiation Laboratory, University of California, Berkeley.*—A method based upon the results of the Lomon-Feshbach (LF) empirical fitting procedure has been established whereby a given potential may be simply tested for its capability of providing an adequate charge-independent description of nucleon-nucleon scattering to 300 Mev. The view is taken that the scattering is better represented by replacing the (in general) strongly energy-dependent scattering phase shifts with a set of suitably defined logarithmic derivatives Γ_{JL}. These, when evaluated at a "characteristic interaction distance" $\hat{r}$, will depend at most weakly upon energy. The success of the LF model in the interval 0 to 300 Mev is here regarded more generally as establishing this view in the above energy range. By means of a variational principle it is shown that $\hat{r}$, which plays the role of an effective range, has a state-independent value in agreement with the "core" radius of LF. It is then only necessary to find the behavior with energy of the parameters Γ_{JL}, as determined by a given potential, in order to test whether or not the latter is capable of giving a charge-independent description of the scattering. The method will be illustrated in S states with static potentials.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

IA7. Nucleon-Nucleon Scattering at High Energies by the Lévy Potential.* H. GELERNTER AND R. E. MARSHAK, *University of Rochester.*—The numerical solution of the Schrödinger equations for nucleon-nucleon scattering by an arbitrary potential has been coded for the I.B.M. 650 Magnetic Drum Electronic Computer. Coupling between states is treated exactly, and phase shifts are computed in the parity representation. All states to $L=3$ inclusive are calculated, except that the $^3G_3$ and $^3H_4$ states are included where they are coupled to lower states. The potential derived by Lévy was examined in the form adopted by Blatt and Kalos.[1] The parameters that Blatt and Kalos find to fit best the low-energy and deuteron data have been found to give poor agreement at 100, 150, and 300 Mev, despite qualitative arguments for their plausibility.[2] The triplet coupled $J=3$ and $J=4$ phase shifts are not small, and indeed, it is quite probable that the $J=5$ phase shifts are not negligible, due to the exterme singularity and long tail of the tensor potential. Total cross sections for $n-p$ scattering are about twice the experimental values. Further studies indicate that agreement is not improved by varying parameters within reason.

* This work was supported by an International Business Machines research endowment grant and assisted by the U. S. Atomic Energy Commission.
[1] J. M. Blatt and M. H. Kalos, Phys. Rev. **92**, 1563 (1953).
[2] M. M. Lévy and R. E. Marshak, *Proceedings of the 1954 Glasgow Conference* (Pergamon Press, 1955).

IA8. High-Energy Electron-Nuclear Scattering. H. MENDLOWITZ, *National Bureau of Standards.*—A transformation similar to that of Foldy-Wouthuysen[1] is performed to obtain a resolution of the Dirac four-component spinor into two two-component spinors in the field-free case. When there is a static electric interaction, we are able to expand the Hamiltonian, in this representation, in terms of the inverse kinetic energy rather than in terms of the inverse rest energy. The approximation of Yennie *et al.*[2] for high-energy electron-nuclear scattering is readily obtained and the effects of neglecting the rest mass can be ascertained. At lower energies, where the mass energy is not negligible, it is found that the scattering will give the gross aspects rather than the details of the nuclear charge distribution, as is well known. Also, the correction terms are of a nonlocal nature and contain spin-dependent terms. These latter effects can be neglected at higher energies.

[1] L. Foldy and S. A. Wouthuysen, Phys. Rev. **78**, 29 (1950).
[2] Yennie, Ravenhall, and Wilson, Phys. Rev. **95**, 500 (1954).

IA9. Elastic Scattering of Electrons and Positrons by Nuclei. J. A. DOGGETT AND L. V. SPENCER, *National Bureau of Standards.*—Preliminary to systematic calculations of electron penetration, we have programmed the computation of the Mott cross section[1] for the National Bureau of Standards automatic digital computer (SEAC). The essential part of the code is a routine for computing complex gamma functions. Results will be presented for $Z=6$, 13, 29, 50, 82, and 92 and energies 10, 4, 2, 1, 0.7, 0.4, 0.2, 0.1, and 0.05 Mev. Comparisons will be made with earlier results for extreme relativistic energies ($\beta\approx 1$) by Feshbach,[2] as well as with results for $Z=80$ by Bartlett and Watson[3] and for $Z=92$ by Yadav.[4] Tabulations now cover complete ranges of Z and energy for both electrons and positrons.

[1] N. F. Mott, Proc. Roy. Soc. (London) **A124**, 425 (1929).
[2] H. Feshbach, Phys. Rev. **88**, 295 (1952).
[3] J. H. Bartlett and R. E. Watson, Proc. Am. Acad. Arts Sci. **74**, 53 (1940).
[4] H. N. Yadav, Proc. Phys. Soc. (London) **A68**, 348 (1955).

IA10. Coulomb Scattering of Relativistic Electrons by Nuclei.* NOAH SHERMAN, *University of California, Livermore.*—The Mott[1] series for the Coulomb scattering of electrons by point nuclei have been evaulated numerically with the aid of the UNIVAC. Calculations of the series for $F(\theta)$ and $G(\theta)$, the scattering cross section, and the polarization asymmetry factor, $S(\theta)=\delta^{\frac{1}{2}}$, were performed for scattering by nuclei of charge Z equal to 80, 48, and 13 at ratios of electron to light velocities, $\beta=v/c$, equal to 0.2, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9. Since the series are slowly and conditionally convergent, two transformations were employed in the summation. The first transformation[2] extracts $(\sin\theta/2)^{-6}$ from the original series, thus eliminating the need for those Legendre polynomial terms which would be required to approximate a negative power of $(\sin\theta/2)$ at small angles. The other is the well-known Euler transformation. The data will be presented and their accuracy discussed.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] N. F. Mott, Proc. Roy. Soc. (London) **A135**, 429 (1932).
[2] Yennie, Ravenhall, and Wilson, Phys. Rev. **95**, 500 (1954).

IA11. Two-Group Model for the Photonuclear Effect.* J. S. LEVINGER, *Louisiana State University.*—We have made two attempts to combine the quasi-deuteron model (qd) with the independent particle model (IPM) for the nuclear ground state in order to calculate the bremsstrahlung-weighted cross section[1] (σ_b) for the photonuclear effect. (1) We use qd wave functions for neutron-proton pairs in an S-state, multiplied by a "damping factor" $\exp(-r\delta)$; (2) we apply the IPM for photon energy less than E_{qd}, and the qd model for photon energy greater than E_{qd}, assuming ordinary $n-p$ forces. The results for σ_b are sensitive to the values chosen for the parameter used: δ or E_{qd}. If we choose δ about 3×10^{12} cm^{-1}, or if we choose E_{qd} about 50 Mev, we find that σ_b is about 10% less than the IPM value.

* Supported by the National Science Foundation.
[1] J. S. Levinger, Phys. Rev. **97**, 122 (1955).

TUESDAY AFTERNOON AT 2:00

Manhattan Center, Gold Room

(H. D. HAGSTRUM presiding)

Electron Physics

Invited Papers

J1. Recent Field-Emission Studies. W. P. DYKE, *Linfield College.* (30 min.)

J2. Field Ion Microscopy. E. W. MULLER, *Pennsylvania State University.* (30 min.)

Contributed Papers

J3. Dependence of Secondary Electron Emission Upon Angle of Incidence of 1.3-Mev Primaries.* R. A. SHATAS, J. F. MARSHALL, AND M. A. POMERANTZ, *Bartol Research Foundation.*—The dependence of the yield of secondary electrons upon the angle of incidence of the primaries has been investigated utilizing the "sandwich" arrangement described previously.[1] When the path through the target is sufficiently short so that scattering of the primary electrons is negligible, the theoretically predicted relationship $\delta(\theta°)=\delta(0°)\sec\theta°$ is obtained. Thus, for example, with 2 mg/cm²Al, the sec θ dependence holds for angles up to 60°. The results indicate that owing to the scattering of secondaries, they may be regarded essentially as being emitted isotropically with respect to the direction of motion of the primary beam. At larger angles, a departure from the aforementioned simple dependence upon primary path length occurs as a consequence of the effect of primary scattering.

* Assisted by the Office of Ordnance Research, U. S. Army.
[1] Pomerantz, Marshall, and Shatas, Phys. Rev. **95**, 635 (1954).

J4. Transmission Secondary Electron Emission from Metals and Insulators. E. J. STERNGLASS AND M. M. WACHTEL, *Westinghouse Research Laboratories.*—Measurements of the yield and energy distribution of electrons emitted from the exit side of thin films under electron bombardment provide a convenient method for comparing the secondary emission process in metals and insulators. Such measurements were carried out on layers of Au (25–100 A), KCl (1200–5200 A), and SiO (120 A) supported on fine metal mesh, using primary energies from 0.5–20.0 kev. For Au, the energy distribution was found to be substantially independent of the distance traveled by the secondaries to the exit surface. In contrast, for KCl (energy gap 7.1 ev), a progressive shift towards energies below 8 ev took place with increase of the escape distance. When most of the secondaries were formed near the exit surface, the energy distribution curves for SiO, Au, and KCl were found to approach the same form. This suggests that the secondary formation process is essentially the same in metals and insulators, and that differences in yield derive primarily from the diffusion process undergone by the secondaries.

J5. Feasibility of Transmission Secondary Emission for Image Intensification. M. M. WACHTEL AND E. J. STERNGLASS, *Westinghouse Research Laboratories.*—Experiments were undertaken to test the properties of Au-KCl transmission secondary emission dynodes[1,2] for imaging purposes. Preliminary experiments measured the yield, energy distribution of the secondaries, and deterioration under bombardment for a series of film thicknesses. Resolution experiments were conducted using two multiplying stages and an output phosphor in a demountable cathode-ray tube. All gap widths were 0.2 inch. Each dynode accelerating voltage was 3 kv and that of the output gap 10 kv. Gold dots thick enough to stop 3-kev electrons were deposited on the front surface of the first dynode in four arrays of 10, 40, 80, and 120 dots per linear inch. Under these conditions, 80 dots per inch were resolved at an over-all current gain of 16, no magnetic focusing being employed. The results show that the image undergoes appreciable degradation only in the electron flight across the gaps and not in the films themselves.

[1] E. J. Sternglass and M. M. Wachtel, Bull. Am. Phys. Soc. **30**, No. 7, 11 (1955).
[2] E. J. Sternglass, Rev. Sci. Instr. (to be published).

J6. Surface Ionization Phenomena. JAY ZEMEL, *U. S. Naval Ordnance Laboratory.*—It has been customary to describe the ratio of the ion-to-atom currents I_+/I_a emitted from a tungsten filament by the Langmuir-Saba equation $I_+/I_a=\omega_+/\omega_a[(1-\mathfrak{r}_+)/(1-\mathfrak{r}_a)]\exp[e(\varphi-I)/KT]$ where ω_+/ω_a is the ratio of statistical weights of the ion to atom; $\mathfrak{r}_+$ and $\mathfrak{r}_a$ are the reflection coefficients of the ion and atoms, respectively; I is the ionization potential of the atom; φ is the thermionic work function of the surface. Since it is known that patches of varying work function exist on tungsten surfaces, a calculation has been made to include this effect. The calculated values for I_+/I_a were obtained using a 4 patch model with (φ_{patch}) =4.35, 4.56, 4.68, and 5.35 volts for either potassium or sodium. The fractions of the surface covered by the patches, f_{patch}, were then obtained by fitting to the data of Phipps *et al.*[1–3] Good agreement was obtained. Some of the significance of this effect on the interpretation of surface ionization phenomena will be discussed.

[1] M. Copely and T. Phipps, Phys. Rev. **48**, 960 (1935).
[2] Hendricks, Phipps, and Copely, J. Chem. Phys. **5**, 868 (1937).
[3] Johnson and Phipps, J. Chem. Phys. **7**, 1039 (1939).

J7. Emission of Thermal Electrons From Ferroelectric Materials. P. H. FANG, *Philco Corporation.*—The current of thermal electrons emitted from $BaTiO_3$ in a sheet form at a temperature region of 700 to 1000°K and under a field of 100 v/cm is measured in a simple diode structure. The work function shows considerable dependence on both temperature and field. The resulting current density is of the order of $\mu a/cm^2$. A similar experiment is carried out with $PbTiO_3$. In this case, the emission is one order of magnitude higher than that of $BaTiO_3$. The emission mechanism which leads to such high currents from these ordinarily insulating materials is explained by the following considerations: (1) the semiconducting behavior of these materials at high temperatures, (2) the effect of the high dielectric constant on the electron flow, (3) the existence of a surface state even at temperatures far above the usual Curie point of transition (this surface state is electrically active and constitutes a favorable dipole layer with a high field intensity), and (4) the effect on the work function, due to the crystal modifications and phase transformations, is shown over a relatively broad temperature region.

J8. Infrared Quenching of Photoconductivity and Luminescence. FRANK MATOSSI, *U. S. Naval Ordnance Laboratory.*—The influence of infrared radiation on luminescence and photoconductivity can be described by the following simplified

model: Infrared radiation excites electrons into empty centers and/or empties filled traps. The dependence of the radiation effects on time (dynamic quenching curves) of photoconductors continuously excited to equilibrium conduction or luminescence are obtained by considering the particle balance between the energy levels of the simplified model. A good qualitative theoretical explanation of Bube's results[1] on the conductivity quenching of CdS is obtained after the adjustment of the following parameters: transition probabilities from conduction band to centers and traps, efficiencies of infrared stimulated center-filling and trap-emptying, and equilibrium densities of photoconduction electrons and empty centers. In certain cases it is necessary to assume the existence of two kinds of centers with different values of the parameters. Simple approximate formulas for computing numerical values of the parameters from characteristic features of the dynamic quenching curves are derived.

[1] H. Bube, Phys. Rev. **99**, 1105 (1955).

J9. Operational Characteristics of PbS Cells at Saturation Level Light Intensities.* JOHN R. HOLMES AND RICHARD H. BRODY, *University of Southern California.*—An experiment is in progress in which several frequency-dependent parameters of Pbs cells are being measured at unusually high light levels. These parameters are signal-to-noise ratio and time constant of cell response. The light levels have been chosen sufficiently high to assure operation of the PbS cells in the nonlinear region of cell output-to-input ratio. Previous work has indicated a dependance of saturation level on frequency of signal chopping. Detailed results will be presented.

* Work partly supported by Office of Naval Research.

J10. Variation with Oxygen Treatment of Photocurrent in PbS Films. R. H. HARADA AND H. T. MINDEN, *Chicago Midway Laboratories.*—Outgassed PbS films are *n*-type and highly conducting. When a film is exposed to oxygen the conductance g decreases 3 to 5 orders of magnitude, reaches a minimum and then increases. The sign of the thermoelectric power changes at the minimum in conductance. The photoconductance Δg also decreases with initial oxygen treatment, but as the oxygen pressure is raised and g begins to increase, Δg also increases. This anomalous effect is explained by the following theory. Oxygen acceptors adsorbed on PbS films reduce the photocurrent by lowering the free carrier mobility. If enough oxygen is present, however, the Fermi level is lowered sufficiently, so that some of the oxygen surface states are emptied. These states can act as special electron traps, from which recombination does not take place. The lifetime photoholes becomes essentially the dwell time of the photoelectrons in the traps, and the photocurrent is enhanced.

TUESDAY AFTERNOON AT 2:00

Grand Ballroom

(H. E. GOVE presiding)

Reactions of Transmutation and Nuclear Energy Levels, P through Au: General

JA1. *Q*-Value Measurements for Phosphorus and Chlorine.* D. M. VAN PATTER, C. P. SWANN, W. C. PORTER, AND C. E. MANDEVILLE, *Bartol Research Foundation.*—Nuclear reaction energies have been measured using a double-focusing magnetic spectrometer at an observation angle of 90°, in conjunction with the ONR-Bartol Van de Graaff generator. Energy calibrations included Po alpha particles, the $Al^{27}(p,\alpha)Mg^{24}$ reaction energy, and the $Li^{7}(p,n)Be^{7}$ threshold. From a preliminary analysis of the measurements for reaction groups from targets containing P and Cl, the following Q-values were obtained.

$P^{31}(p,\alpha)Si^{28}$	$Q=1.92\pm0.015$ Mev
$Cl^{35}(p,\alpha)S^{32}$	$Q=1.85\pm0.015$ Mev
$Cl^{37}(p,\alpha)S^{34}$	$Q=2.99\pm0.02$ Mev
$Cl^{37}(p,\alpha)S^{34*}$	$Q=0.89\pm0.015$ Mev
$P^{31}(p,p')P^{31}$	$Q=-1.27\pm0.01$ Mev
$Cl^{35}(p,p')Cl^{35}$	$Q=-1.22\pm0.01$ Mev
$Cl^{35}(p,p')Cl^{35}$	$Q=-1.765\pm0.01$ Mev

The identification of the two inelastic proton groups to the Cl^{35} isotope is primarily based on preliminary results of Endt *et al.*[1] A survey was also made at $E_p=3.06$ Mev for inelastic proton groups from P^{31} corresponding to levels from 0- to 1.44-Mev excitation. Only one group ($Q=-1.27$ Mev) was observed, consistent with recent measurements[2] of the gamma radiation emitted from P^{31} bombarded by protons.

* This research was supported by the U. S. Air Force, through the Office of Scientific Research of the Air Research and Development Command.

[1] P. M. Endt (private communication).
[2] J. W. Olness and H. W. Lewis, Phys. Rev. **99**, 654(A) (1955).

JA2. Levels in P^{31} from the $Si^{30}(p,\gamma)P^{31}$ Reaction. E. B. PAUL, G. A. BARTHOLOMEW, H. E. GOVE, AND A. E. LITHERLAND, *Chalk River Laboratories.*—The gamma rays from the reaction $Si^{30}(p,\gamma)P^{31}$ have been studied in the range of proton energies from 1.7 to 2.3 Mev using targets enriched to about 90% in Si^{30}, and about 25 resonances were observed. At two of these resonances, 1.73 and 1.82 Mev, angular distributions of the gamma rays leading to the ground state were measured. These showed both to have spin 3/2, with positive parity for the 1.73-Mev resonance and, with less certainty, positive parity also for the 1.82-Mev resonance. Triple (p,γ,γ) correlation measurements using two geometries were made at each resonance and showed that the spin of the 1.26-Mev level is probably 3/2+ and that of the 2.23-Mev level is $\geq 5/2+$.

JA3. Inelastic Proton Scattering from Iron. W. W. BUECHNER AND A. SPERDUTO, *M.I.T.*—The proton groups scattered from thin iron targets of natural isotopic abundance have been studied at angles of observation of 30, 45, 90, and 130° with an incident proton energy of 7.04 Mev and at 130° with an incident energy of 6.63 Mev. The proton groups were analyzed with a broad-range magnetic spectrograph, and their changes in energy with angle and incident energy have been used to determine the isotopes from which they arise. These studies indicate excited states in Fe^{54} at 1.41,2.54, 2.57, 3.16, and 3.34 Mev and in Fe^{56} at 0.36, 0.85, 2.08, 2.66, 2.94, 2.96, 3.12, 3.37, 3.45, and 3.60 Mev. A number of weaker groups have been observed whose assignment will require experiments with isotopically enriched targets.

JA4. Excitation Curve and Angular Distributions for the $Ni^{58}(p,p'\gamma^{1.45})Ni^{58}$ Reaction.* M. S. MOORE, J. P. SCHIFFER, AND C. M. CLASS, *The Rice Institute.*—The excitation curve for this reaction was studied from $E_p=2.5$ to 4.5 Mev. Sixty

resonances were observed, all having $\Gamma \leq 4$ kev, in the region corresponding to 6.9- to 8.4-Mev excitation in Cu^{59}. No off-resonance yield of the 1.45-Mev γ ray was observed. Lower limits for the resonance cross sections ranged from 1 to 19 mb/sterad, when assuming $\Gamma = 4$ kev. Angular distributions of the 1.45-Mev γ ray were studied for thirty-seven resonances. Assuming the 1.45-Mev state in Ni^{58} to be 2^+, nineteen distributions were fit by assuming a $5/2^+$ compound state, and seventeen by a $\frac{3}{2}$ state. Only one distribution was isotropic, consistent with a $\frac{1}{2}$ state.

* Supported in part by the U. S. Atomic Energy Commission.

JA5. Proton Capture Resonances in Ni^{58} and Ni^{60}. C. R. GOSSETT, J. W. BUTLER, AND H. D. HOLMGREN, *Naval Research Laboratory.*—Separated isotopes of Ni^{58} and Ni^{60} have been bombarded with protons accelerated by the NRL 2-Mev Van de Graaff generator. The yield of capture gamma rays was determined as a function of proton energy from 0.6 to 1.6 Mev. Thin targets of the isotopes were prepared by electroplating onto silver backings. The gamma rays were detected with the use of a 3-in. $\times$3-in. NaI (Tl) crystal and a 20-channel analyzer. In the case of Ni^{58}, the gamma excitation function was confirmed by observations on the 81-second positron activity of Cu^{59}. Resonances were observed for the following proton energies on Ni^{58}: 855, 947, 1009, 1099, 1226, 1307, 1315, 1375, 1423, 1521, 1539, and 1581 kev. For Ni^{60} they were: 725, 895, 1029, 1066, 1078, 1132, 1167, 1197, 1209, 1239, 1247, 1313, 1319, 1323, 1331, 1343, 1347, 1371, 1381, 1415, 1431, 1451, 1461, 1465, 1483, 1491, 1515, 1519, 1529, 1539, 1567, 1578, 1589, 1600, 1607, and 1620. All the resonances appeared to be less than 1 kev wide. Gamma-ray energies and relative intensities will be presented.

JA6. Nuclear Resonance Fluorescence in Ni^{60}.* FRANZ R. METZGER, *Bartol Research Foundation.*—With a gaseous source of $Co^{60}Cl_2$, nuclear resonance fluorescence from the 1.33-Mev level in Ni^{60} has been observed. The molecular form of the source renders the interpretation of the magnitude of the resonance fluorescence effect in terms of the lifetime of the 1.33-Mev level in Ni^{60} difficult. However, in the present case a more direct approach is possible. The resonance fluorescence effect is so large that the reduction of the effect by a nickel absorber can be studied directly. In this way the evaluation of the lifetime becomes independent of the details of the recoil phenomena. The experimental value for the mean life of the 1.33-Mev excited state is $(7.5 \pm 2.5) \times 10^{-13}$ second. This is approximately eight times shorter than the single particle estimate.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

JA7. (Pile n,p) Reactions of Nickel and Barium; Gamma Rays of Co^{58}.* BEROL L. ROBINSON AND RICHARD W. FINK, *University of Arkansas.*—By chemical separation and scintillation spectroscopy, we have identified the following reactions induced in the Oak Ridge reactor:

Reaction	Q-value (Mev)	Effective cross section
$Ni^{58}(n,p)Co^{58}$	-0.3 ± 0.4	30 ± 3 millibarns
$Ni^{60}(n,p)Co^{60}$	-1.53	0.6 ± 0.1 millibarn
$Ba^{132}(n,p)Cs^{132}$	~ 0	0.7 ± 0.2 millibarn
$Ba^{130}(n,p)Cs^{130}$	-0.92	0.2 ± 0.05 microbarn

A neutron flux of 5×10^{11} was assumed in calculating the nickel cross sections; the barium cross sections were determined by comparison with the $Ba^{130}(n,\gamma)$ reaction (6 barns). Q-values are calculated from other nuclear data. Six ppm cobalt impurity would account for the Co^{60} yield observed; however, the target was "specpure" nickel containing <1 ppm cobalt. Reactions of this type establish limits for neutron activation analysis for $(Z-1)$ impurities. During the course of these experiments, a 1.6-Mev gamma ray was observed in Co^{58} decay. Its intensity is 0.005 compared to the 0.81-Mev gamma ray. This transition corresponds to the 1.6 Mev state observed in the $Fe^{57}(d,p)Fe^{58}$ reaction.[1]

* Supported in part by the National Science Foundation and the U. S. Atomic Energy Commission.

[1] McFarland, Shull, Elwyn, and Zeidman, Phys. Rev. 99, 655 (1955); National Research Council Nuclear Data Card No. 55M23 (June 6, 1955).

JA8. Nuclear Reaction $Au^{197}(n,p)Pt^{197}$.* R. A. PECK, JR., *Brown University.*—The $Au(n,p)$ reaction is being studied using neutrons of approximately 14 Mev and 400μ Ilford C2 emulsions, in a "poor geometry" arrangement. No shielding is attempted, plates and target being exposed together to approximately 10^9 neutrons/cm^2. The proton energy spectrum suggests a cluster of groups, probably not resolvable with the present technique, in the first 2 Mev above the ground state, plus fairly resolved groups at excitations of approximately 2.5, 4.7, 7.8, and 9.7 Mev in the residual Pt nucleus. The low-energy continuum yield indicates a nuclear temperature of 1 Mev at 14.4-Mev excitation.

* Supported in part by the U. S. Atomic Energy Commission.

JA9. Nuclear Reactions Produced by Nitrogen on Boron and Oxygen. H. L. REYNOLDS,* D. W. SCOTT,† AND A. ZUCKER, *Oak Ridge National Laboratory.*—The following nuclear reactions were detected from the bombardment of elemental boron and oxygen by energetic nitrogen ions: (1) $B^{10}(N^{14},O^{15})Be^9$, (2) $B^{10}(N^{14},N^{13})B^{11}$, (3) $B^{10}(N^{14},C^{11})C^{13}$, (4) $B^{10}(N^{14},F^{18})Li^6$, (5) $B^{11}(N^{14},p)Na^{24}$, (6) $O^{16}(N^{14},2p)Al^{28}$, and (7) $O^{16}(N^{14},F^{18})C^{12}$. The thick target yields as a function of energy for these reactions were differentiated to obtain the cross sections as a function of energy. Reactions 2 and 3 can be identified as stripping reactions by comparison with similar proton induced reactions and by comparison with previously studied nitrogen induced reactions. Reactions 1 and 4 are compared to proton-induced reactions in Na^{23} which lead to the same residual nuclei. The nitrogen-induced reactions are more probable by factors of 4 and 2 respectively, after barrier penetration corrections have been made, indicating that these nitrogen- and proton-induced reactions proceed through somewhat different mechanisms. The reactions in oxygen are compared to similar proton-induced reactions in Si^{29}.

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JA10. Nitrogen-Induced Nuclear Reactions in Aluminum. A. ZUCKER, W. H. WEBB,* AND H. L. REYNOLDS,† *Oak Ridge National Laboratory.*—Aluminum foils were bombarded with 25.5-Mev nitrogen ions and the following radioactive reaction products were separated chemically and identified: C^{11}, N^{13}, F^{18}, Na^{24}, Cl^{38}, K^{38}, P^{32}. Cross sections for the three reactions, $Al^{27}(N^{14},N^{13})Al^{28}$, $Al^{27}(N^{14},3p)Cl^{38}$, $Al^{27}(N^{14},p2n)K^{38}$, were measured by varying the incident beam energy from 25.5 Mev to 19.5 Mev. It was found that over this energy region the cross section for the $(N^{14},p2n)$ reaction is about fifty times greater than for the $(N^{14},3p)$ reaction, as would be expected from the statistical theory for the decay of the compound nucleus. A search was made for Si^{31} and Mg^{27}. The upper limits for the respective yields are 3×10^{-13} and 9×10^{-13} nuclei formed per incident particle at 25.5 Mev. The cross section of the reaction $Al^{27}(N^{14},N^{13})Al^{28}$ is 2×10^{-28} cm^2 at 24.5 Mev. This reaction is probably of the stripping type although its cross section is lower by a factor of about forty than the cross sections for similar reactions previously observed in boron and nitrogen.

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† Now at University of California Radiation Laboratory, Livermore, California.

JA11. Energy Distribution of Light Particles from Nitrogen-Induced Nuclear Reactions. CHARLES D. GOODMAN AND JOHN L. NEED, *Oak Ridge National Laboratory.*—The energy distributions of protons, deuterons, and alpha particles produced by bombarding thin targets of several light elements with 25-Mev nitrogen ions from the ORNL 63-inch cyclotron have been measured. The distributions show peaks from reactions leading to the ground states and several excited states of the residual nuclei and a continuum from unresolved higher states. The detector consists of a proportional counter—NaI crystal telescope. The rate of energy loss of the particle is measured by the proportional counter and the energy by the NaI crystal. The dE/dx and E pulses are lengthened and then applied respectively, to the vertical and horizontal axes of an oscilloscope. When both pulses are at their peaks the electron beam is unblanked producing a spot on the oscilloscope screen. This is viewed by a photomultiplier which gates a 20-channel pulse-height analyzer for the E pulse. Particle type selection is accomplished by masking the cathode-ray tube appropriately.

JA12. Internal Conversion in Coulomb-Excited Odd A Nuclei.* E. M. BERNSTEIN AND H. W. LEWIS, *Duke University.*—A study has been made of internal conversion electrons from electric excitation of odd A elements in the rare earth region. Thin targets, made by evaporation of natural elements on thick Al or Cu backings, were bombarded by alpha particles up to 4 Mev. In favorable cases, cascades from second excited states are observed as well as first excited state transitions. The elements and transitions observed are (transition energies in kev): Eu^{153}, 84, 111; Gd^{155}, 61; Gd^{157}, 56; Ho^{165}, 96, 122; Lu^{175}, 114, 139; Ta^{181}, 137, 165; Re^{185}, 125; Re^{187}, 135; Ir^{191}, 129; Ir^{193}, 140. Where two transition energies are given, the second is a cascade. For all transitions except Gd, K/L ratios have been determined. An analysis of multipolarity mixtures based on K/L ratios and branching ratios for the second excited states will be presented. Preliminary analysis indicates that the ratio of $M1$ to $E2$ in both transitions in Eu^{153} is about 2 to 1, while transitions in Ho^{165}, Lu^{175}, and Ta^{181} are mainly (>90%) $M1$. Bombardment of Gd revealed electron lines at 53 and 48 kev, which are almost certainly the L conversion lines from first excited states. The existence of these levels was suggested by Heydenburg and Temmer on the basis of gamma-ray measurements of the second excited states.

* Supported in part by U. S. Atomic Energy Commission.

JA13. Spallation Events Induced in Uranium and Thorium with High-Energy Protons.* M. LINDNER AND R. N. OSBORNE, *University of California, Livermore.*—A radiochemical study was made of the nonfission products of uranium and thorium irradiated with protons of energy from 100 to 340 Mev from the 184-inch cyclotron at UCRL Berkeley. The spallation cross section of uranium for 340-Mev protons is $\sim 0.23\times10^{-24}$ cm², and that for thorium is $>0.32\times10^{-24}$ cm². Curves for σ *vs* mass number are given for the elements Np, U, Pa, Th, Ac, and Ra for U or Th at 340 Mev. The rapidly decreasing yield for light uranium isotopes—in contrast to the behavior of other elements from uranium spallation, and in contrast to the behavior expected from a knock-on process followed by nuclear evaporation alone—shows that the light uranium nuclei must be responsible for most of the high-energy-proton-induced fission observed by other investigators. This results in an apparent average number of neutrons lost, per proton lost, of ~3 for thorium, but of only ~1.7 for uranium. Excitation functions show that most of the spallation product yields have thresholds at ~100 Mev.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

TUESDAY AFTERNOON AT 2:00

Terrace Room

(R. SHERR presiding)

Radioactive Nuclei, I

K1. Radiations of Br^{82} and Rb^{82}.* N. BENCZER AND C. S. WU, *Columbia University.*—Both Br^{82} and Rb^{82} decay to Kr^{82} with the emission of a complex gamma-ray spectrum. The energy and the intensity of the internal conversion electron spectrum of the eight gamma lines of Br^{82} were determined in the solenoidal magnetic spectrometer. The cascades between the eight gamma lines were investigated with a selective coincidence scintillation spectrometer. The β^- spectrum of Br^{82} is simple and has a maximum energy of 0.435 Mev. The upper limit of any higher energy β^- group is less than 0.6%. The internal conversion spectrum of Rb^{82} was also investigated and compared with that of Br^{82}. Out of the 14 gamma lines reported previously[1,2] the eight gamma lines of Br^{82} appear also in Rb^{82} with the exact same intensity ratio. Out of the six remaining gamma lines three were not found; the other three decayed with a half-life shorter than the half-life of Rb^{82}. The β^+ spectrum of Rb^{82} is also simple, and has an end point energy of 0.783 Mev. The energy level diagram of Kr^{82} and the Q values of the reactions will be discussed.

* This work was partially supported by the U. S. Atomic Energy Commission.

[1] C. M. Huddleston and A. C. G. Mitchell, Phys. Rev. **88**, 1350 (1952).
[2] H. T. Easterday, UCRL 2172 (1953).

K2. Inner Bremsstrahlung and Energy Levels in the Decay of Sb^{119}. J. L. OLSEN, L. G. MANN, AND M. LINDNER, *University of California, Livermore.*—Te^{119} was produced by the reactions $Sb(d,xn)Te^{119}$ at 190 Mev and $Sn(\alpha,xn)Te^{119}$ at 39 Mev. Sb^{119} was then obtained in high purity by chemical separation from the purified Te parent. The decay takes place by orbital electron capture to the 23.83±0.03 kev* state in Sn^{119}.[1] The following quantities were measured: Sb^{119} half-life, 38.0 hr, $Sb^{119}-Sn^{119}$ decay energy, 587±10 kev, total internal conversion coefficient of the 23.8 kev gamma ray, 6.3±0.4, half-life of the 23.8 kev state, $1.85\pm0.1\ 10^{-8}$ sec, and the L_I/L_{II+III} conversion ratio, *>3. These measurements support the decay postulated in reference 1. The gamma continuum accompanying s-electron capture was $8.55\pm1.3,\ 10^{-5}$ quanta per electron capture, in agreement with the Glauber and Martin theory.[2] The p-state spectrum intensity equals the s-spectrum at 150 kev, in disagreement with Glauber's prediction of ~100 kev.[2] This work was performed under the auspices of the U. S. Atomic Energy Commission.

* These measurements were by J. M. Hollander on a permanent magnet spectrograph.

[1] M. Goldhaber and R. D. Hill, Revs. Modern Phys. **24**, 179 (1952).
[2] R. J. Glauber and P. C. Martin, Phys. Rev. **95**, 572 (1954); also private communication with Professor Glauber.

K3. Gamma Radiation from the Interaction of 4.4 Mev Neutrons with Isotopes of Tellurium, Copper, and Nickel.* ROLF M. SINCLAIR, *Westinghouse Research Laboratories.*—Gamma radiation from 4.4±0.1 Mev neutron bombardment of separated isotopes (supplied by Oak Ridge) was observed with a single crystal NaI(Tl) spectrometer.[1] Only the more strongly excited gamma rays can be detected from these small samples (5–30 grams). Gamma rays assigned to inelastic scattering are (energies in Mev): Te^{125}, none; Te^{126}, 0.68±0.02, 1.38±0.04; Te^{128}, 0.76±0.02; Te^{130}, 0.83±0.02; Ni^{58}, 1.01 ±0.01, 1.46±0.02; Cu^{63}, 0.65±0.01, 0.97±0.01, 1.34±0.03, 1.43±0.05; Cu^{65}, 1.12±0.02. The Te^{126} gamma rays agree in energy with the known[2] first and second excited states, although the strong 0.74 Mev second-first state transition was not detected. The Te^{128} and Te^{130} gamma rays are presumably from the first states. The Ni^{58}, Cu^{63}, and Cu^{65} isotopic assignments confirm those made by energy comparison with other experiments.[3] A 1.35±0.02 Mev gamma ray is assigned to Ni^{60} by elimination.

* Supported by the joint program of the Office of Naval Research and U. S. Atomic Energy Commission.
[1] R. M. Sinclair, Phys. Rev. **99**, 1351 (1955).
[2] M. L. Perlman and J. P. Welker, Phys. Rev. **95**, 133 (1954).
[3] R. B. Day, Int. Conf. on Peaceful Uses of Atomic Energy, A/Conf. 8/P/581 (1955) (Unpublished).

K4. Gamma Radiation from the Disintegration of Silver 105. R. W. HAYWARD AND D. D. HOPPES, *National Bureau of Standards.*—The gamma radiation from the disintegration of silver 105 has been reinvestigated[1] with a scintillation coincidence spectrometer. Gamma rays are observed with the following energies and relative intensities: 64 (40), 157 (weak), 184 (weak), 281 (60), 319 (weak), 331 (weak), 345 (100), 393 (weak), 443 (24), and 654 kev (36). All those labeled weak are not resolved in the scintillation spectrum and are detected by means of conversion electrons in a magnetic-lens spectrometer or by gamma-gamma coincidences. All resolved gamma rays are in coincidence with palladium x-rays. The following coincident pairs are observed: (64,281), (319,331), and (443, 654). K to L conversion electron ratios identify the 64 and 281 kev transitions as magnetic dipole and the 345 transition as electric quadrupole. The total disintegration energy of silver 105 is greater than 1122 kev. Features of the disintegration scheme based on experimental evidence and nuclear model considerations will be presented.

[1] R. W. Hayward, Phys. Rev. **85**, 760(A) (1952).

K5. Extranuclear Effects and the Directional Correlation of the Cd^{114} Gamma Rays.* R. M. STEFFEN AND L. M. NOBLE, *Purdue University.*—The directional correlation of the 722–556 kev gamma-gamma cascade in Cd^{114} following K-capture in In^{114} has been measured by means of a coincidence analyzer with differential pulse height selection. The disturbing effect of the positrons which are present in the In^{114} decay, was eliminated almost completely by the energy analysis. The directional correlation observed on ten In^{114} sources of very different physical and chemical structure (dilute aqueous solutions viscous liquids, ionic crystals, metal, etc.) was found to be independent of the state of the source. The extranuclear effects on the Cd^{114} gamma-gamma correlation reported by Daubin and Hamilton[1] could not be confirmed. The correlation function extracted from these measurements is given by

$$W(\theta)=1+(0.099\pm0.005)P_2(\cos\theta)+(0.010\pm0.07)P_4(\cos\theta)$$

and confirms the 4−2−0 angular momenta assignment to the Cd^{114} levels.[2]

* Work supported in part by the U. S. Atomic Energy Commission.
[1] S. C. Daubin and D. R. Hamilton, Phys. Rev. **99**, 683 (1955).
[2] R. M. Steffen, Phys. Rev. **83**, 166 (1951); J. N. Brazos and R. M. Steffen, Phys. Rev. **99**, 1645(A) (1955).

K6. The Auger Cascade in Xenon. ARTHUR H. SNELL AND F. PLEASONTON, *Oak Ridge National Laboratory.*—Internal conversion in Xe^{131m} (E_γ=0.163 Mev, $T_{\frac{1}{2}}$=12 days) produces vacancies in the internal electronic shells of the Xe^{131} atom, and if these vacancies are not filled through "fluorescent" x-ray emission, a cascade of Auger events may take place in which the vacancies multiply as they proceed outward through the electronic structure. We have measured the resulting distribution in charge of the product atoms, using a source volume at low pressure (5×10^{-6} mm Hg), an electric collecting field, and magnetic deflection to separate the ions in various charge states. Applied voltages were made inversely proportional to the charge states, so that the electric collecting and focusing forces were uniform from charge to charge. Preliminary results for the charge spectrum of Xe^{131} are as follows (N.M. signifies "not measured"):

Charge	Relative intensity	Charge	Relative intensity	Charge	Relative intensity
1	N.M.	7	76	13	9
2	N.M.	8	100	14	5
3	7	9	72	15	3
4	20	10	54	16	1
5	35	11	28	17	0.5
6	48	12	15	≥18	N.M.

K7. Decay of Rhenium-188. V. R. POTNIS,* V. S. DUBEY,† AND C. E. MANDEVILLE, *Bartol Research Foundation*‡.—The 18-hour rhenium was formed by slow neutron irradiation of metallic rhenium in the Brookhaven reactor. Gamma rays were detected at energies 150, 480, 630, 660, 820, 910, 1130, 1300, 1600, and 1700 kev. In the same order, the relative intensities of the unconverted quantum radiations are 101, 12, 16 (combined intensities of 630 and 660 kev gammas), 6.5, 5.8, 2.7, 2.2, 2.1, and 1. The angular correlation function of the 480 kev–150 kev cascade has been measured at five different angles and is given by

$$W(\theta)=1-0.876(\pm0.123)\cos^2\theta+1.032(\pm0.082)\cos^4\theta.$$

The shape of the curve is in accord with a 2−2−0 scheme as might be expected for an even-even nucleus such as Os^{188}. The extent of the anisotropy at 180° suggests that the 480 kev transition is a mixture of $E2$ and $M1$.

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† On leave of absence from Agra College, Agra, India.
‡ Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

K8. The Decay of Os^{185} (94 Day) and Os^{193} (31 Hour). S. V. NABLO AND M. W. JOHNS, *McMaster University.*—The internal and external conversion spectra of Os^{185} and Os^{193} have been studied with a high resolution beta ray spectrometer for energies above 150 kev. Transitions of energies 0.1603, 0.2334, 0.5920, 0.6458, 0.7177, 0.8715, and 0.8789 Mev follow the electron capture decay of Os^{185} and involve six excited states in Re^{185}. A Fermi analysis of the complex beta spectrum accompanying the 31-hour decay has revealed groups of the following end-points and intensities: 1136±5 kev (40%), 1063 kev (33%), 997 kev (5%), 855 kev (12%), and 677 kev (10%). Gamma rays were measured with the following energies: 0.2508, 0.2807, 0.3214, 0.3621, 0.3876, 0.4604, and 0.5582 Mev. This information may be ascribed to transitions involving five excited states in Ir^{193}. Experiments are in progress to extend the measurements to lower energies and test the proposed decay schemes by coincidence techniques. The half-lives of these nuclides have been measured and are found to be 94.3±0.5 days (Os^{185}) and 31.5±0.1 hours (Os^{193}).

K9. Long Lived Platinum-193.* R. A. NAUMANN, *Princeton University.*—The 4.3 day activity assigned to platinum-193 has been shown to be an M-4 isomeric transition in platinum-193 and the half-life limits for decay of the ground state of this isotope to iridium-193 have been set as shorter than 1 hour or greater than 74 days by previous workers. An unreported activity, which has shown no decay over a four month period, has been observed in platinum fractions isolated from normal and 192-enriched platinum samples

after slow neutron irradiation in the MTR reactor. The amounts of long-lived activity produced in these samples are consistent with the 18-fold increase in abundance of platinum-192 in the enriched sample over the normal sample. The radiation accompanying this activity appears to consist solely of 10 kev X-radiation which has been characterized both by aluminum and copper absorption and detection with a sodium iodide scintillation spectrometer. This radiation is attributed to iridium L X-radiation following L electron capture in platinum 193. A search for positron, beta, or harder X and gamma radiation has given no indication of such radiations being associated with the activity. This activity is chemically identical with platinum and does not follow chemical separations of a number of other elements. An upper limit for the half-life is set at about 500 years.

* This work was supported by the U. S. Atomic Energy Commission, the Higgins Scientific Trust Fund, and in part by a grant in aid of the E. I. du Pont de Nemours Company.

K10. Angular Correlation of Gamma Rays in Pb^{204m}.† J. R. HUIZENGA, V. E. KROHN, AND S. RABOY, *Argonne National Laboratory.*—The anisotropy of the 375–899-kev prompt cascade in Pb^{204m} has been measured in an attempt to determine the spin assignments of the excited states and the multipole character of the three gamma rays in the cascade.[1] Sources were prepared by bombarding PbO, enriched in Pb^{204}, with fast neutrons in the Argonne Research Reactor, CP-5, and producing the 1.1 hour state by inelastic scattering. A second series of sources were prepared by chemically separating the bismuth activities produced by bombarding lead with 22-Mev deuterons in the Argonne cyclotron and then eluting the Pb^{204m} with 0.1N HCl from a Dowex A-1 anion resin column containing the 12-hour Bi^{204} parent. The anisotropy obtained from the two series of measurements is 0.163 ± 0.010. This result is consistent with the level scheme $4(E-2)\times2(E-2)0$. Further delayed-coincidence measurements on the 912–375-kev and 912–899-kev gamma ray pairs were undertaken with sources obtained from the Bi^{204}. The anisotropy found for the 912–899-kev gamma ray pair is 0.414 ± 0.015; and for the 912–375-kev pair, 0.398 ± 0.011 is obtained. These results are consistent with the scheme, $9(E-5)4(E-2)2(E-2)0$.

† Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] V. E. Krohn and S. Raboy, Phys. Rev. **95**, 1354 (1954); Phys. Rev. **97**, 1017 (1955).

K11. Cascade Decay of Rotational States in Deformed Nuclei of Odd Mass. G. M. TEMMER AND N. P. HEYDENBURG, *DTM, Carnegie Institution of Washington.*—We have observed $X-X$, $X-\gamma$, and $\gamma-\gamma$ coincidences in $_{65}Tb^{159}$, $_{67}Ho^{165}$, and $_{71}Lu^{175}$ following Coulomb excitation with 6-Mev alpha particles and using energy selection in both channels. We had previously found $\gamma-\gamma$ coincidences in $_{63}Eu^{153}$ and $_{73}Ta^{181}$.[1] Hence the rotational bands, characteristic of strongly deformed nuclei with odd mass number,[2] which we had inferred from our gamma ray spectra,[1] are put on a firm basis. Furthermore, we found the cascade radiation from second- to first-rotational state in the above cases at about 79, 112, and 136 kev, respectively. In $_{72}Hf^{177}$ and $_{72}Hf^{179}$ we saw the cascades at about 138 and 141 kev. A summary of our preliminary results follows for branching ratios (*crossover/cascade*):

Nucleus	$_{63}Eu^{153}$	$_{65}Tb^{159}$	$_{67}Ho^{165}$	$_{71}Lu^{175}$	$_{72}Hf^{177}$	$_{72}Hf^{179}$
Branching ratio	3.9	0.30	0.21	0.92	4.8	0.81

The branching ratios for the de-excitation of the second rotational states yield the $M1-E2$ mixtures of the cascades; their relation to the intrinsic and collective g-factors[2] will be discussed. Similar work on elements with no available enriched sotopes ($_{66}Dy$, $_{68}Er$, $_{70}Yb$) is in progress.

[1] N. P. Heydenburg and G. M. Temmer, Phys. Rev. **100**, 150 (1955).
[2] A. Bohr and B. R. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **27**, No. 16 (1953).

K12. Gamma Rays from U^{235}.* C. W. MALICH, *U. S. Naval Research Laboratory.*—Absolute intensities of some gammas from U^{235} were measured by comparing enriched and ordinary uranium in a NaI spectrometer. Energies and (photons per 100 disintegrations of U^{235}) are: 146 ± 3 kev (13 ± 6) and 188 ± 2 kev (55 ± 7) from U^{235}, 209 ± 4 kev (3.7 ± 0.7) probably from U^{235}, and 349 ± 4 kev (0.03 ± 0.01) unassigned. The latter is not due to RaB or AcC. There are no other gammas between 260 kev and 450 kev with an intensity greater than 0.01. Radiation from Th^{230} and Th^{231} limited our accuracy at lower energies. Gammas previously reported[1] at 289 kev and 386 kev (with relative intensities apparently an order of magnitude too large) are probably due to accidental coincidences of the 188 kev gammas and of K x-rays and 188 kev gammas.

* Work supported and sources supplied by U. S. Atomic Energy Commission.
[1] Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 605 (1953).

TUESDAY AFTERNOON AT 2:00

Panel Room

(THORNTON READ presiding)

Metals

KA1. Distribution of Electrons Scattered in Solids.* J. AROL SIMPSON, L. MARTON, AND T. F. MCCRAW, *National Bureau of Standards.*—Further measurements[1] have been made on the energy and angular dependence of 20-kev electrons scattered by foils a few hundred angstroms thick. The apparatus used is that previously described,[2] although detailed refinements of the magnetic analyzer have improved the energy resolution to better than 0.08%. It is now possible to resolve both the elastic and characteristic loss peaks and follow their intensity variation throughout the entire angular range from the forward direction to angles greater than $\frac{1}{10}$ radian. In the materials studied, Au, Al, Ni, Fe, C, Al_2O_3, and Formvar, the general behavior is similar. To characterize the results, we have adopted the ratio of the intensity of the zero energy loss peak to the intensity of the most prominent characteristic loss peak. This ratio is usually greater than one in the forward direction, less than one between 2×10^{-3} and 2×10^{-2} radian and greater than one, again, beyond this angle. The effect of foil thickness on this behavior will be shown and possible interpretations discussed.

* This work supported in part by the Office of Naval Research.
[1] Phys. Rev. **90**, 495 (1955).
[2] Rev. Sci. Instr. **26**, 855 (1955).

KA2. Interpretation of Electron Characteristic Energy Losses. LEWIS B. LEDER AND L. MARTON, *National Bureau of Standards.*—The characteristic energy losses of electrons in fifteen metals and compounds have been compared with the

fine structure found on the short wavelength side of the x-ray K-absorption edge for these same materials. Such a comparison was made by Cauchois[1] for the case of aluminum. However, she compared the characteristic losses with the maxima of transmission rather than with the maxima of absorption of the x-ray fine structure. A striking correlation is found when the maxima of absorption are used. We find also that the energy loss spectra are similar for metals which are neighbors in the periodic table, and that there is some dependence on the crystal lattice constant. This correlation leads us to believe that some of the characteristic energy losses can be interpreted in terms of interband transitions wherein the energies of the final states are the same as those found in the case of the x-ray absorption fine structure.

[1] Y. Cauchois, Acta Cryst. **5**, 351 (1952).

KA3. Scattering of Fast Electrons by Conduction Electrons.* J. J. QUINN AND R. A. FERRELL, *University of Maryland.*—Experimentally a fast electron passing through a metal foil loses energy only in discrete multiples of an energy characteristic of the metal. The Bohm-Pines theory interprets the characteristic energy loss as an excitation of collective electron plasma oscillations. It also accounts for the angular dependence of the scattering below a cut-off angle corresponding to a minimum plasma wavelength.[1] At greater angles the scattering must be treated as excitation of electrons above the Fermi sea, but simple one-electron theory yields a continuum of small energy losses. We have taken the Coulomb interactions into account by approximately diagonalizing the total energy matrix for the electron system. Due to exchange of excitation among the electrons, one of the energy eigenvalues separates from the continuum and is raised by an amount $\hbar\omega_P \cdot \theta_{cE}/\theta$ where ω_P is the plasma frequency, θ_{cE} the cutoff angle, and θ the angle of scattering. The excitation into this discrete state predominates at the cutoff, but excitation into the lower lying continuum becomes important at larger angles.

* Research supported by the Office of Naval Research.
[1] R. A. Farrell, Phys. Rev. **99**, 647(A) (1955), and a paper submitted to *The Physical Review*.

KA4. Lattice Scattering of Fast Electrons by Thin Metal Foils.* J. L. WARREN AND R. A. FERRELL, *University of Maryland.*—The electron-lattice interaction which determines the resistivity and superconductivity of metals is subject to direct investigation by electron scattering experiments. Buckingham[1] finds theoretically that the lattice scattering, being practically elastic, makes a contribution to the slowing down of fast electrons which is negligible compared to that from inelastic electron-electron scattering. The electrons passing through a metal foil and scattered by the lattice can, however, be separated experimentally from those inelastically scattered, and the angular dependence of the lattice scattering has been successfully measured.[2] We have made an approximate calculation of this angular dependence for transit times short compared to the lattice vibrational periods. For room temperature a classical treatment suffices, and we find a Gaussian distribution with mean standard deviation proportional to the square roots of the temperature and foil thickness and inversely proportional to the incident energy. At low temperatures a quantum-mechanical treatment is necessary and will be discussed.

* Research supported by the Office of Naval Research.
[1] M. J. Buckingham, Proc. Phys. Soc. (London) **A66**, 601 (1953).
[2] Marton, Simpson, and McCraw, Phys. Rev. **99**, 495 (1955).

KA5. Effect of Electron-Lattice Interaction on the Debye Temperature of Cubic Metals at Low Temperatures. C. B. CLARK, *U. S. Naval Research Laboratory and University of Maryland,* AND R. A. FERRELL, *University of Maryland.*—Recent experimental data[1] on the specific heats of various metals indicate a drop of the Debye temperature, Θ_D, followed by a gradual rise, with increasing temperature. De Launay[2] and Bhatia[3] have studied the effects of the conduction electrons on the lattice specific heat and it is clear from their work that these effects contribute significantly to the drop in Θ_D. We have made a similar study at long wavelengths from the standpoint of the collective electron-ion interactions, following Staver[3] and Bardeen and Pines,[3] and have calculated the electron contribution to the curvature of the Θ_D curve at absolute zero. All contributions to the curvature are additive at low temperatures, and that from Born-von Karman theory can be dealt with separately. In case of isotropy the curvature calculation is particularly simple and will be presented. The anisotropic case will also be discussed.

[1] W. S. Corak *et al.* Phys. Rev. **98**, 1699 (1955); W. F. Giauque and P. F. Meads, J. Am. Chem. Soc. **63**, 1897 (1941), (Cu); D. H. Parkinson and J. E. Quarrington, Proc. Phys. Soc. (London) **A68**, 762 (1955), (Na).
[2] J. de Launay, J. Chem. Phys. **21**, 1975 (1953); A. B. Bhatia, Phys. Rev. **97**, 363 (1955).
[3] T. Staver, Doctoral thesis, Princeton University (1952) (unpublished); J. Bardeen and D. Pines, Phys. Rev. **99**, 1140 (1955).

KA6. Overlap and Temperature Effects in Magnesium Alloys. PAUL M. MARCUS, *Carnegie Institute of Technology.*—New precision lattice constants for Mg−In[1] alloys are analyzed using Jones' picture of effective electronic stress arising as filling of Brillouin zone changes. Observed rapid changes in c/a as electron concentration changes are attributed to sharp stresses arising when Fermi surface is close to a zone boundary. Using three constants from cellular calculations of Trlifaj,[2] free electron perturbation theory to describe the form of the overlap band, and including the effect of finite temperature, the observed variation of c/a is explained within 15% for values of overlap deficiency between ± 2 atomic %. Variation of effective electronic stress with temperature contributes to thermal expansion, β, and is calculated to give a substantial fraction of observed anistropy of β in pure Mg. Experiment proposed as critical test of this picture compares anisotropy of β for pure Mg and an alloy. These temperature effects form a generalization to anisotropic lattices of the electronic effect on β of Visvanathan.[3]

[1] Von Batchelder and Raeuchle, 13th Annual Pittsburgh Diffraction Conference, November 3, 1955.
[2] M. Trlifaj, Czechoslov. J. Phys. **1**, 110 (1952).
[3] S. Visvanathan, Phys. Rev. **81**, 626 (1951).

KA7. Brillouin Zone Studies. VI. Core Potential Effects in Dilute Magnesium Alloys. A. I. SCHINDLER AND E. I. SALKOVITZ, *Naval Research Laboratory.*—Hall coefficient measurements have been extended and now include dilute alloys of either Ag, Cd, Al, In, Tl, Sn, or Pb in Mg. Overlap effects have been found in all trivalent or tetravalent additions to Mg. Ag and Cd additions appear to show no such effect. The Hall data for Cd additions have been carried out to 13.7 at % Cd. The Hall coefficient decreases as a monotonic function of composition and changes sign at approximately 7.7 at % Cd in Mg. Since Cd is a member of the second column of the periodic table, such a behavior may be attributed to the influence of alloying additions on the ratio of mobilities of holes to electrons. In the thermoelectric power data of these same dilute Mg alloys,[1] it was found possible to separate a contribution due to the core potential from one due to the valence electrons of the alloying element. In the Hall data a similar, although apparently more complicated separation can also be made for the alloys containing either Ag, Al, In, or Pb.

[1] Kammer, Salkovitz, and Schindler, Bull. Am. Phys. Soc. **30**, No. 7 (1955).

KA8. Short-Range Order Coexisting With Long-Range Order in Cu_3Au. B. W. ROBERTS, *General Electric Research Laboratory,* AND G. H. VINEYARD, *Brookhaven National Laboratory.*—Diffuse x-ray scattering from a single crystal of Cu_3Au was observed at $T/T_c \cong 0.995$ where the long-range order parameter, $S=0.85$. By annealing at low temperatures

nearly perfect order was obtained. A difference curve yields the diffuse scattering attributable to short-range order coexisting with the long-range order state of S=0.85. Analysis of the diffuse intensity in absolute units gives values of the first three short-range order coefficients. The first coefficient is found to be close to the perfect order value: $\alpha_1=-0.33$. Within experimental error the observed coefficients fit both the Cowley[1] theory and a random long-range order model equally well.

[1] J. M. Cowley, Phys. Rev. **77**, 669 (1950).

KA9. Cohesive Energy of Potassium.* SAM BERMAN, JOSEPH CALLAWAY, AND ROGER D. WOODS, *University of Miami.*—The cellular method has been used to calculate the cohesive energy of metallic potassium. The crystal potential was taken from a self-consistent field with exchange for the potassium ion. Approximate wave functions for s and p states of the valence electron were found from orthogonalized plane waves and used to compute the exchange interaction from the Hartree-Fock equation. This interaction is significantly different in s and p states. The energy of the lowest state was found to be -0.453 rydberg, and the effective mass was 85.6% of the free electron mass. The Coulomb, exchange, and correlation interactions of the valence electron were calculated according to the free electron approximation and give -0.004 rydberg. The cohesive energy was found to be 17.3 cal/mole, which can be compared with the experimental result, 22.6. Although this result is not so good as that yielded by the quantum defect method, it is a considerable improvement over an earlier calculation by Gorin.[1]

* Research supported by the Office of Naval Research.
[1] E. Gorin, Physik. Z. Sowjetunion **9**, 328 (1936).

KA10. Creep of Aluminum Single Crystals. J. WEERTMAN, *Naval Research Laboratory.*—Creep experiments were made on aluminum single crystals in the 250°C to 610°C temperature range and 2×10^8 to 10^9 dynes/cm^2 stress range. All specimens (dimensions: 2-inch length, 0.093-inch diameter) were cut from one single crystal which was grown by the soft mold technique and thus had identical orientations. An activation energy of creep of approximately 36 000 cal/mole was found. The creep rate is proportional to (stress)^3 over the stress range investigated. The apparatus used is similar to one described by Metzger.[1]

[1] M. Metzger, Rev. Sci. Instr. **24**, 184 (1953).

KA11. On the Energy of Formation and Migration of Vacancies in Metals.* A. S. NOWICK, *Yale University.*—Recent estimates, based on precise measurements of resistivity after quenching of pure gold,[1] indicate that the formation energy of a vacancy (H) is 65%, and the activation energy (J) for migration is 35% of the total self-diffusion "activation energy" (Q). Quenching experiments on solid solution alloys[2] show quite different results, with $H/Q=0.40-0.45$. This lower ratio implies a high vacancy concentration at the melting point (at least 0.2%). Since solid solutions show annealing behavior after irradiation similar to the corresponding pure metals, it is difficult to attribute the above discrepancy to a basic difference between alloys and pure metals. Furthermore, there are other evidences[3] for a low H/Q ratio for pure metals. It is suggested that a possible reason for the discrepancy between different investigators is related to the presence of more than one type of point defect which contributes to self-diffusion and which can be quenched in from high temperatures.

* Part of a program supported by the Office of Ordnance Research.
[1] J. W. Kauffman and J. S. Koehler, Phys. Rev. **97**, 555 (1955).
[2] A. E. Roswell and A. S. Nowick, J. Metals **5**, 1259 (1953); C. Y. Li and A. S. Nowick, Phys. Rev. **98**, 1531(A) (1955).
[3] B. G. Lazarev and O. N. Ovcharenko, Doklady Akad. Nauk. S.S.S.R. **100**, 875 (1955).

KA12. On the Linear Rate of Transformation of White to Gray Tin.* J. H. BECKER, *National Bureau of Standards.*—Rates of transformation[1] of white to gray tin have been studied as a function of temperature, impurity content, mechanical treatment, and sample geometry. The rate was determined from the motion of the gray-white tin boundary observed visually with a low-power microscope and calibrated eyepiece. This method allows accurate rate determinations even when several gray-white tin boundaries are present, and distinguishes between "nucleaton time" and "linear growth rate." Annealed samples of high-purity tin ($20\times1\times0.025$ mm) were "seeded" at one end and transformed at temperatures between 5 and -115°C. The rates at the two extreme temperatures were about 10^{-3} mm/hr; the maximum rate of 1 mm/hr occurred at about -32°C. An absolute rate theory will be presented[2] which indicates that the temperature dependence of the rate near the transition temperature (13.2°C) is dominated by the white-gray tin free energy difference, while at low temperatures it is dominated by the heat of activation to the activated state. Heavily cold-worked samples indicated considerably shorter "nucleation times" than annealed samples, but the same linear growth rate.

* Research supported by the Office of Naval Research.
[1] Survey article: C. E. Homer and A. C. Watkins, Metal Ind. (London) **60**, 275 (1942).
[2] Compare with: F. Cagle, Jr., and H. Eyring, J. Phys. Chem. **57**, 942 (1953).

KA13. Effects of Radiation Quenching, Ion-Bombardment, and Annealing on Catalytic Activity of Pure Nickel and Platinum Surfaces.* R. F. WOODCOCK AND H. E. FARNSWORTH, *Barus Research Laboratory, Brown University.*—Investigations on surface catalysis for hydrogenation of ethylene at a cleaned nickel surface[1] have been extended to platinum with similar results. Radiation quenching of a platinum sheet from 1000°C produces an activity 3 times that obtained after the sheet has been quenched and subsequently annealed at 700°C. After positive ion bombardment with argon the activity is 10 times that obtained after bombardment and subsequent annealing. At present nickel is being used to catalyze the reaction $H_2+D_2\rightarrow HD$. Preliminary results following heat treatment indicate that after quenching from 800°C the activity is 3 or 4 times greater than that obtained after annealing at 500° to 600°C. These results suggest that the high activity following radiation quenching or argon-ion bombardment is the result of the presence of lattice defects, at the surface of the crystal lattice, which are largely removed by subsequent annealing.

* Assisted by Office of Ordnance Research, U. S. Army, and by the National Science Foundation.
[1] R. F. Woodcock and H. E. Farnsworth, Phys. Rev. **98**, 1152 (1955).

KA14. Normal Modes of Vibration of One-Dimensional Lattices with Free Ends.* RICHARD F. WALLIS, *Applied Physics Laboratory.*—Vibration frequencies have been calculated for finite one-dimensional lattices in which the point masses alternately have the values m_α and m_β, $m_\alpha<m_\beta$. Only nearest neighbor Hooke's law interactions are considered. The end atoms are assumed to interact only with their nearest neighbors on the interior of the lattice and are otherwise free. If the numbers of points having masses m_α and m_β are equal, there exists a single mode whose frequency lies at the middle of the "forbidden" gap between the optical and acoustical bands. For this "surface" mode the displacement of the points from their equilibrium positions decreases roughly exponentially from the end having the lighter point mass. For the case of N points of mass m_β and $N+1$ points of mass m_α there exist two modes whose frequencies lie in the "forbidden" gap provided $(m_\alpha/m_\beta)<N/(N+1)$. These modes correspond to symmetric and antisymmetric displacements. The displacements are largest for the end atoms and decrease roughly exponentially toward the center of the lattice.

* This work supported by the Bureau of Ordnance, Department of the Navy.

TUESDAY AFTERNOON AT 2:00

Boston Room

(A. PAIS presiding)

Theoretical Physics, IV

L1. Transformation of Relativistic Wave Equations BEHRAM KURSUNOGLU,* *Yale University.*—A unitary transformation is found which achieves an exact separation of positive and negative energy states of a Dirac particle interacting with an external electromagnetic field. The $(v/c)^2$ approximation to the motion of a Dirac particle agrees with the Foldy and Wouthuysen result. The transformation is extended to quantized fields and to relativistic two-body equations. The second-order electromagnetic mass effects in the quantized Dirac equation appear, in the nonrelativistic limit, as the time derivatives of the electric terms of the nonrelativistic Hamiltonian without the radiative corrections. These mass effects in the nonrelativistic Hamiltonian are proportional to $(1/mc)^3$. Construction of unitary transformation operators for the $ps-ps$ meson theory and for the Bethe-Salpeter equation are also discussed.

* Now at E.U.Rs. (Turkish General Staff), İlmi İştişare Kurulu, Ankara, Turkey.

L2. Hyperfine Splitting in the 2S State of Hydrogen.* M. H. MITTLEMAN, *University of California, Livermore.*—Calculations of the radiative corrections to the hyperfine splitting in hydrogen coupled with the Breit relativistic correction predict a known value to order α^2 for the ratio of the hyperfine splittings in the $1S$ and $2S$ states. Recent measurements of the hyperfine splitting in the $2S$ state would make possible the detection of deviations from this ratio of order α^3. Any attempt to calculate the α^3 corrections to hyperfine splitting would be difficult because of the many processes which are possible to this order. However, the calculation of the ratio to order α^3 is a reasonable task. This is so because many of the possible processes are dependent on the state only through the square of the wave function at the origin and through the derivative of the wave function at the origin. These quantities introduce only the factor 8 in the ratio. This sort of reasoning eliminates the contributions from the 4th- and 6th-order radiative corrections leaving only the extended effects of the second-order radiative corrections. These have been calculated and are being evaluated with the aid of machine computation. Numerical results will be presented at the meeting. Arguments to show that reduced mass corrections and finite proton size effects cannot contribute to the ratio to this order will be given.

* Most of this work was performed while the author was at Columbia University.

L3. Radiative Corrections to the Ground State Energy of Helium. P. K. KABIR AND E. E. SALPETER, *Cornell University.*—Very accurate theoretical values for the nonrelativistic ionization potentials of helium-like atoms are now available. All relativistic corrections of order $Z^4\alpha^2Ry$ and $Z^3\alpha^2Ry$ have also been calculated.[1] The radiative corrections of order $Z^4\alpha^3Ry$, the Lamb shift to lowest order, have been estimated previously.[2] Accurate numerical calculations of Bethe's[3] "average excitation energy" k_0 for the helium atom will be presented, based on oscillator strengths calculated from the Hylleraas 6-parameter nonrelativistic ground-state wave function. The most important transitions are found to be those to the $(1s)$ (continuous p) ^1P states. There are a number of radiative corrections of order $Z^3\alpha^3Ry$, some of which contain $\log\alpha$ as a factor. Calculations, based on quantum electrodynamics and a perturbation method, will be presented for the coefficient of $Z^3\alpha^3\log\alpha Ry$, which is rather small.

[1] Sucher and Foley, Phys. Rev. **95**, 966 (1954); T. Kinoshita (unpublished).
[2] H. Håkansson, Arkiv Fysik **1**, 555 (1950).
[3] Bethe, Brown, and Stehn, Phys. Rev. **77**, 370 (1950).

L4. Some Properties of Solutions of the Bethe-Salpeter Equation. D. A. GEFFEN, *Oak Ridge National Laboratory.*—Solutions to the Bethe-Salpeter equation for spin $\frac{1}{2}$ particles can be expressed in terms of Dirac matrices. This has the advantage of exhibiting explicitly the spin and symmetry properties of the solutions. For total $J=0$, one can obtain a set of four coupled equations in four dependent and two independent variables. For $J>0$ more equations are necessary. In the ladder approximation, for $J=0$, four coupled, second order partial differential equations in r and relative time t are obtained. By making Wick's[1] analytic continuation it is possible to obtain series expansions of the general solutions about $R=(r^2+x_4^2)^{\frac{1}{2}}=0$ of the form $\sum_m c_m R^{\alpha+m} f_m(x_4/R)$, provided f_m are finite polynomials. Series expansions were investigated for the $^1S_0$ state in positronium and the $^3P_0$ state for pseudoscalar meson theory, with similar results for the two cases. Regular sets of solutions exist with the exponent α a simple function of the coupling constant and a quantum number n determining the order of the polynomials $f_m(x_4/R)$. The result for the pseudoscalar meson case is of particular interest since the nonrelativistic limit yields a singular tensor force requiring a cut-off procedure.

[1] G. C. Wick, Phys. Rev. **96**, 1124 (1954).

L5. Intrinsic Moments of Elementary Particles. JANE PEASE, *Northeastern University,* AND ROBERT L. PEASE, *Tufts University.*—The linear equation for a system in an external electromagnetic field $A_\mu=(ie/\hbar c)^{-1}\mathfrak{A}_\mu$ is assumed to be

$$[i\beta^\mu(\partial_\mu-\mathfrak{A}_\mu)+k]\psi=0$$

where the matrices β^μ obey general commutation rules[1] of degree n imposed by requirements of relativistic invariance:

$$\sum_{r=1}^{n!}\sigma_r[(\beta^{\mu_1}\beta^{\mu_2}-a_1{}^2g^{\mu_1\mu_2})\cdots(\beta^{\mu_{n-1}}\beta^{\mu_n}-a_p{}^2g^{\mu_{n-1}\mu_n})]=0$$

(for n even $=2p$, and a similar rule for n odd $=2p+1$). By considering permutations of a product of $(\partial_\mu-\mathfrak{A}_\mu)$ operators, a systematic procedure for extracting the intrinsic moments of the system is developed. A specific calculation is made for the magnetic dipole moment in the case of $n=4$, $a_1{}^2=1$ $a_2{}^2=0$, and the result compared with that of Harish-Chandra.[2]

[1] H. J. Bhabha, Revs. Modern Phys. **21**, 451 (1949).
[2] Harish-Chandra, Proc. Int. Conf. (Cambridge, 1946) 185 (1947); Proc. Roy. Soc. (London) **192**, 195 (1947).

L6. Spinor Fields and Gravity.* F. J. BELINFANTE, *Purdue University.*—Unlike DeWitt,[1] we use in gravitational electron theory the fourleg formalism, with uniform[2] representation of spinors. The 10-component metric $g_{\mu\nu}$ follows from the 16 fourleg components $h_{\alpha'}{}^\mu$, but not conversely. In the matter Lagrangian, not all fourleg derivatives $\partial_\lambda h_{\alpha'}{}^\mu$ combine to metric derivatives $\partial_\lambda g_{\mu\nu}$. If $p_\mu{}^{\alpha'}$ is canonically conjugate to $h_{\alpha'}{}^\mu$, therefore, $S^{\alpha'\beta'}=p_\mu{}^{\alpha'}h^{\mu\beta'}-p_\mu{}^{\beta'}h^{\mu\alpha'}$ does not vanish. Invariance under fourleg rotations yields six primary "fourleg constraints" $S^{\alpha'\beta'}=\cdots$ besides the four primary and four secondary "coordinate constraints." This should reduce the

number of "independent" canonical gravitational variables to the usual number. As a preliminary to quantization we derive the Hamiltonian and the various secondary constraints for the interacting fields. Our ultimate goal is formulating a canonical transformation between the Heisenberg-quantized "independent" variables of the fields in curved space, and conventionally quantized fields satisfying linear equations without interaction in an arbitrarily chosen flat model of space.

* Supported in part by the National Science Foundation.
[1] B. S. and C. M. DeWitt, Phys. Rev. **87**, 116 (1952).
[2] F. J. Belinfante, Physica **7**, 305 (1940).

L7. Quantized Field Theory in the Hamilton-Jacobi Formalism. I. The Method, with Application to the Free Klein-Gordon Field. HANS FREISTADT, *Newark College of Engineering.*—A method is developed, and applied to the free Klein-Gordon field, for modifying the author's Hamilton-Jacobi formalism for classical field theory[1] in such a way as to describe field quantization, in a manner analogous to that employed by Bohm[2] for quantum mechanics of particles. Although the modified Hamilton-Jacobi equations, as well as the explicit, modified, nonlinear field equations do not contain functionals of the field variables on a space-like surface, but only functions of the field variables at a space-time point, they are implicitly tied to families of space-like surfaces through a normal vector field which cannot be eliminated. Furthermore, the modified Hamilton-Jacobi equation in each case can be found only from the Schrödinger equation for the quantized field system, not directly by a uniform method of generalizing the classical equations. The consistency of the present method with the usual formalism of field quantization is shown by means of a continuity equation, but no explicit solution, which would exhibit the presence of particle-like quanta, are given. Problems peculiar to fermions are not discussed.

[1] H. Freistadt, Phys. Rev. **97**, 1158 (1955).
[2] D. Bohm, Phys. Rev. **85**, 180 (1952).

L8. Four-Dimensional Formulation of the Nyquist Formula. J. WEBER, *Institute for Advanced Study and Princeton University.*—A four-dimensional formulation is given for the Nyquist formula. The result is useful in the quantum theory of fields We define a dissipation tensor $d_{\mu\alpha}$ representing absorption of energy by the field when driven by a system of "charges" and "currents." For a four potential field, the vacuum expectation value for field operators at the space time points x and x' is

$$\langle A_\mu(x)A_\alpha(x')\rangle_0=\frac{\hbar}{\pi}\int_0^\infty \frac{d_{\mu\alpha}(x,x',\omega)}{\omega}d\omega.$$

L9. Double Inferential State Method and Negative Energy Fields. SATOSI WATANABE, *U. S. Naval Postgraduate School.*—A natural development of the formalism using "double inferential state-vectors," introduced in connection with the consideration regarding symmetry between prediction and retrodiction,[1] leads to a general method dealing with negative energy fields. This method, in essence, is equivalent, though not identical, to Gupta-Bleuler's method of indefinite metric[2] and to Tanikawa's method of super quantization.[3]

[1] S. Watanabe, Revs. Modern Phys. **27**, 179 (1955).
[2] S. N. Gupta, Proc. Phys. Soc. (London) **63**, 681 (1950); K. Bleuler, Helv. Phys. Acta **23**, 567 (1950); K. Bleuler and W. Heitler, Progr. Theoret. Phys. **5**, 600 (1950).
[3] Y. Tanikawa, Progr. Theoret. Phys. **5**, 692 (1950); **7**, 193 (1952).

L10. Approach to Elementary Particle Structure. T. F. MORRIS, *McGill University.*—Field theories for which an incompatibility exists between the mass and space-time coordinate operators have been considered.[1] If the mass operator is in diagonal form each coordinate operator possesses both diagonal and off-diagonal matrix elements with respect to the various mass states. The diagonal elements are designated as the mean coordinate operator. An interaction term which is localized with respect to the coordinate operators is shown to be nonlocalized with respect to the mean coordinate operators. This result may be interpreted, within the framework of this theory, as an effect which arises from the statistical space-time structure possessed by a particle in a definite mass state.

[1] T. F. Morris, Phys. Rev. **99**, 650(A) (1955).

WEDNESDAY MORNING AT 9:30

Terrace Room

(E. L. QUIMBY presiding)

Symposium on Biophysics

M1. Information Storage and Transfer in Living Matter. G. GAMOW, *George Washington University.* (30 min.)

M2. Viruses and Macromolecules Studied with the Electron Microscope and Ultracentrifuge. R. W. G. WYCKOFF, *National Institutes of Health.* (30 min.)

M3. Viruses and Macromolecules Studied by Bombardment with High-Energy Particles. E. C. POLLARD, *Yale University.* (30 min.)

M4. Biological Effects of Ionizing Radiations. G. FAILLA, *Columbia University.* (30 min.)

WEDNESDAY MORNING AT 9:30

Manhattan Center, Gold Room

(P. H. MILLER presiding)

Semiconductors, I

MA1. Phonon Drag Effect and Nernst Coefficient. P. J. PRICE, *IBM Watson Laboratory.*—The Nernst coefficient, B, of a semiconductor should show an anomaly due to the phonon drag effect similar to that in the thermoelectric power Q. For an extrinsic semiconductor, provided Boltzmann statistics may be applied to the carriers,

$$B=\left[\frac{k}{e}\left(\frac{3}{2}\pm\frac{\epsilon-\zeta}{kT}\right)\pm Q\right]\left(\frac{\mu^H-\lambda^H}{c}\right)$$

(the upper sign for n-type), where ζ is the Fermi energy and, for the carrier band: ϵ is the band-edge energy, μ^H the Hall mobility, and λ^H the corresponding "mobility" giving the Hall angle of the component of drift velocity due to thermodiffusion, including the phonon-drag thermodiffusion. Thus the contribution to B resulting from the phonon drag effect equals that to Q times $\pm(\mu^H-\lambda^H)/c$. From Herring's analysis[1] of the anomaly in Q for Geballe and Hull's p-type "Sample 7", the above result predicts an anomaly in B at 50°K of order -2 microvolts per gauss-degree.

[1] C. Herring, Phys. Rev. **96**, 1163 (1954) (see Fig. 2).

MA2. Capacity Changes in the Surface Layer of a Semiconductor. W. L. BROWN, *Bell Telephone Laboratories.*—Changes in the electrical capacity associated with surface states and the space charge region at the free surface of a semiconductor have been measured. The space charge capacity per unit area is defined as $C_{sc}=d\Sigma_{sc}/dV_s$ and the surface state capacity as $C_{ss}=d\Sigma_{ss}/dV_s$ where Σ_{sc} and Σ_{ss} are the charges per unit of surface area in the space charge region and in the surface states and V_s is the electrostatic potential of the surface relative to the body of the semiconductor. Both capacities vary with V_s and their variations have been measured in germanium with changes in V_s produced by an external electric field. The capacities are predictable from measurements of the field effect and hence give a check on its interpretation. These predictions indicate that C_{sc} has a minimum at about the minimum in conductance observed in the field effect and that C_{ss} has a minimum whose position depends upon the surface state distribution.[1] In some cases these two minima are well enough separated to be observed directly in the capacity measurements.

[1] W. L. Brown, Phys. Rev. **98**, 1565(A) (1955).

MA3. Electromagnetic Theory of Cyclotron Absorption in Solids.* BENJAMIN LAX AND LAURA M. ROTH, *Lincoln Laboratory, M.I.T.*—Microwave and infrared cyclotron absorption of carriers in solids are examined. For $\omega\tau\approx1$ the absorption may be resonant in semiconductors, or nonresonant in metals. Absorption in the latter case shows an inflection point at $\omega_c\approx\omega+K/\tau$ for circular or linear polarization when B, the magnetic field, is transverse to a semi-infinite slab. K is of the order of unity, ω_c the cyclotron frequency, ω the frequency of the electromagnetic field, and τ the collision time. With B parallel to the surface and τ constant, no cyclotron absorption occurs for a single isotropic carrier. Two carriers in this arrangement show a single inflection which depends on relative concentration and both effective masses. A distributed effective τ, resulting from the anomalous skin effect, leads to inflection points for each carrier and also to line broadening. A high field absorption peak is predicted for semiconductors and semi-metals at microwave and infrared frequencies when $B\approx ne/\omega\epsilon$, where n is the electron density and ϵ the permittivity. Faraday rotation and cyclotron resonance at infrared wavelengths are considered in finite slabs. Theoretical curves similar to those obtained in metals at microwaves are discussed.

* The research reported in this document was supported jointly by the Army, the Navy, and the Air Force, under contract with the Massachusetts Institute of Technology.

MA4. Lattice-Scattering Mobility of Holes in Germanium. H. EHRENREICH, *General Electric Research Laboratory.*—The previously described treatment[1] of the lattice-scattering mobility of holes in germanium, based on the deformable ion model, has been generalized to take into account the possibility that part or all of the atom may be rigidly displaced. For entirely rigid displacements the longitudinal acoustical vibrations are far more important than transverse vibrations, whereas for deformable ions they were seen to be equally important. The additional dilatation produced by rigid displacements brings the magnitudes of the theoretical and observed mobilities at room temperature into agreement for reasonable values of the constant[1] C. Contributions to the electron-phonon interaction arising from relative motions of the two undeformed atoms in the unit cell have been treated more carefully. These consist of optical modes and a further acoustical term. Only one additional undetermined parameter C' needs to be introduced. Although the more rapid temperature variation of the optical modes predominates over the $T^{-1.5}$ dependence characteristic of acoustical modes in the terms involving C', the resultant temperature dependence of the mobility involves the details of the germanium wave functions and potential which determine C and C'. The results for several values of these parameters will be discussed.

[1] H. Ehrenreich and A. W. Overhauser, Phys. Rev. **98**, 1533 (1955).

MA5. Scattering by Ionized Impurities in Semiconductors. N. SCLAR, *United States Naval Research Laboratory.*—The Conwell-Weisskopf and the Brooks-Herring[1] theories for the scattering of free charge carriers by ionized impurities are based on approximations that require that $ka\ll1$ where k is the wave number of conduction electrons and a is the effective range of the ionized impurity. In a semiconductor, k decreases as the temperature, T, decreases and a decreases as the concentration of impurities, N, increases. Thus for those concentrations of impurities and ranges of temperature where ionized impurity scattering is dominant, the available treatments are not applicable. Using a partial wave treatment, analytic expressions have been obtained for the mobility, μ and the Hall coefficient for the range $ka\ll1$. The mean free time for scattering is a function of the parameters ka and $(\pm q^2aD-1)^{\frac{1}{2}}$ where D is the dielectric constant and q is the charge of the carrier. Previous treatments[1] yielded $\mu\alpha T^{\frac{1}{2}}N^{-1}$ for both attractive and repulsive centers. The present treatment for reasonable choices of a yields for repulsive centers $\mu\alpha T^{\frac{1}{2}}N^{-1}$ while for attractive centers there are three cases depending on the values of the parameters. For the three possibilities, we obtain $\mu_1\alpha T^{\frac{1}{2}}N^{-1}$; $\mu_2\alpha T^{\frac{1}{2}}N^{-1}$ and $\mu_3\to\infty$. Numerical computations to cover the intermediate range $ka\sim1$ are in progress.

[1] P. P. Debye and E. M. Conwell, Phys. Rev. **93**, 693 (1954).

MA6. Ionized Impurity Scattering.* F. J. BLATT, *University of Illinois.*—Existing formulas for mobility in the range where ionized impurity scattering limits the relaxation time are based on the Born approximation for calculating the scattering cross section, $A(\epsilon)$. However, in many cases of interest the electron (or hole) energies, ϵ, and the appropriate scattering potentials do not justify use of the Born approximation. In the present work, screened Coulomb potentials have been used to represent ionized impurities and $A(\epsilon)$ calculated by the method of partial waves. At high energies, as expected, A_B and $A_{p.w.}$ agree. However, for electron energies corresponding to thermal energy at $T=100$°K and below, A_B exceeds $A_{p.w.}$ by orders of magnitude. Parametric curves of $A(\epsilon)$ for scattering by ionized donors and acceptors will be shown. The results are of particular interest for InSb and similar compounds in which the impurity ionization energies are so small that ionized impurity scattering dominates even at very low temperatures.

* Supported by the Office of Naval Research.

MA7. Interband Scattering in Semiconductors. H. BROOKS AND W. PAUL, *Harvard University.*—If two different types of energy minima in the conduction band of a semiconductor are sufficiently close in energy, carriers can be scattered between them. Evidence will be reviewed which shows that this situation occurs, for example, in the conduction band of pure germanium at pressures in excess of 12 000 atmospheres, and also in silicon-germanium alloys at substantially lower pres-

sures. A theory for this type of scattering will be presented in terms of a deformation potential model. In the range where such interband scattering becomes appreciable, complex temperature and pressure dependence of the carrier mobility can occur. Data on the resistance of Si–Ge alloys and on the pressure dependence of the resistance of Ge and Ge rich Si–Ge alloys can be rationalized semiquantitatively with this theory, assuming that scattering occurs between (111) and (100) type minima in the conduction band, and these minima have approximately the same curvatures and deformation potentials as in pure Ge and pure Si, respectively, and differ with pressure and composition only as regards their relative position in energy.

MA8. Simultaneous Transport of Heavy and Light Holes in Semiconductors with a Degenerate Valence Band. E. S. RITTNER, *Philips Laboratories.*—A theoretical study has been made of the motion in an *n*-type semiconducting filament of an injected narrow pulse of slow and fast holes subject to drift, diffusion, recombination, and reversible interband transitions. For low injection level and for interband transitions times which are small compared to the recombination lifetime and to the observation time but large compared to the time between collisions, both sets of holes propagate and broaden as a single pulse with a group mobility and diffusivity heavily weighted by that of the slower holes. This explains why only a single pulse is observed at the collector in drift mobility experiments.[1]

[1] N. J. Harrick, Phys. Rev. **98**, 1131 (1955).

MA9. Iron-Doped Silicon. C. B. COLLINS, *General Electric Research Laboratory.*—Electron energy levels have been found in the forbidden band for silicon crystals doped with iron. From resistivity and Hall coefficient measurements as a function of temperature, energy levels have been placed at 0.45 ev from the valence band in *p*-type silicon and at 0.55 ev from the conduction band in *n*-type silicon. Optical ionization energies for impurity photoconductivity have been measured; these provide a check on the energy level values. The solubility of iron in silicon at room temperature has been checked from resistivity and Hall coefficient determinations together with radioactive tracer measurements of the total concentration of iron in the crystal as a function of iron concentration in the melt. Diffusion effects associated with low-temperature heat-treating at 100°C to 200°C and the effect of iron on lifetime will be discussed.

MA10. Some Properties of Manganese-Doped Silicon. R. O. CARLSON, *General Electric Research Laboratory.*—Manganese introduces a deep level in the silicon forbidden band gap at 0.55 ev from the conduction band, acting as a donor impurity. Below 10^{20} cm^{-3} concentration of manganese in the silicon melt, the distribution constant is $\sim 10^{-5}$; above 10^{20} cm^{-3} concentration, the apparent distribution constant is a rapidly increasing function of the concentration of manganese in the melt and the manganese is no longer electrically active in the crystal. The addition of as little as 10^{13} manganese atoms per cm^{-3} to a silicon crystal gives rise to long lifetime traps. Under intrinsic irradiation at 200°K, the Hall coefficient changes sign to correspond to hole conduction. This conversion provides evidence for electron trapping just as the conversion from *p*-type to *n*-type of germanium doped with the transition elements[1] can be explained as due to hole trapping.

[1] W. W. Tyler and R. Newman, Phys. Rev. **98**, 961 (1955).

MA11. Effect of Impurities on Free-Hole Infrared Absorption in *p*-Type Germanium. R. NEWMAN AND W. W. TYLER, *General Electric Research Laboratory.*—The free hole absorption[1,2] in *p*-type germanium (gallium-doped) was studied at 300°K and 77°K as a function of concentration over the range from 10^{15} to 10^{20} acceptors/cm^3. The spectra are modified as the carrier and total impurity concentrations are increased. With increasing concentration the structure in the spectrum becomes less pronounced. The effects observed are consistent with changes in the Fermi level and with nonvertical transitions induced by charged impurity centers. Studies of compensated samples permits a qualitative separation of these effects. The spectrum of holes bound to gallium centers at 20°K was also observed.

[1] Briggs and Fletcher, Phys. Rev. **87**, 1130 (1952); **91**, 1342 (1953).
[2] A. H. Kahn, Phys. Rev. **97**, 1647 (1955).

MA12. Valence Band Structure of Germanium and Silicon. EVAN O. KANE, *General Electric Research Laboratory.*—The interaction of the six valence bands of germanium and silicon is taken into account by solving a sixth order secular equation, expressible as the product of two identical cubics. Explicit calculations of E *vs* k have been made for the principal directions in germanium and silicon. Equation (62)[1] is considered as the leading term of a perturbation expansion of the $k \cdot p$ and spin-orbit perturbations. Estimates of the error from the higher terms in the expansion are made. The leading term yields a split-off band effective mass near $k=0$ which is about 30% too small in absolute value for germanium. For silicon the theoretical procedure is much more accurate. The experimental error in the cyclotron resonance constants makes uncertain the calculations for the upper band of silicon. Further, an ambiguity in sign leads to two possible sets of negative mass constants L, M, N.[1] An objection is raised to the set preferred in reference 1. Optical absorption matrix elements have been calculated using cyclotron resonance constants for the principal directions in germanium. Free carrier absorption is computed. The agreement with experimental data[2] will be discussed.

[1] Dresselhaus, Kip, and Kittel, Phys. Rev. **98**, 368 (1955), Eq. (62).
[2] R. Newman and W. W. Tyler, abstract MA11, this bulletin.

WEDNESDAY MORNING AT 9:30

Panel Room

(A. DE BRETTEVILLE presiding)

Magnetism; Ferroelectricity

N1. Size Variation of the Electrical and Thermal Conductivities of Sodium in Magnetic Fields. G. K. WHITE AND S. B. WOODS, *National Research Council, Canada.*—The variation with magnetic field of the electrical resistance of thin filaments of pure sodium at low temperatures was first observed by MacDonald.[1] An investigation of the thermal conductivity shows a related effect. A 130μ diameter sample was placed in transverse magnetic fields between 0 and 10 kilogauss during

measurements of its thermal and electrical conductivities a ~4.2°K and ~8.3°K. Scattering of the conduction electrons by the walls of the sample, by thermal vibrations and by impurities each play a role in determining these properties. It is found that as the magnetic field is increased from zero, the resistivities of the specimen show a small initial increase, pass through a maximum and then decrease markedly; finally at high fields, where the electron orbits have a radius smaller than that of the specimen, a linear increase with field is observed. Results will be presented with a qualitative interpretation in terms of the electronic mean free paths for energy and momentum exchange.

[1] MacDonald, Nature **163**, 637 (1949).

N2. Magnetic Susceptibility of Copper. R. BOWERS, *Westinghouse Research Laboratories.*—The susceptibility of pure copper has been measured between 300°K and 1.45°K using the Gouy method. The values obtained can be represented by $\chi=(-0.083+0.023/T)\times10^{-6}$ cgs mass units. Two previous measurements[1,2] of the susceptibility between 300°K and 14°K have been reported which are in substantial disagreement with each other. No previous data exist for the susceptibility below 14°K. The temperature dependence found by us is smaller than that reported in the earlier experiments; in particular, we do not find the low-temperature anomaly recorded by Bitter *et al.* About one-fifth of the paramagnetic component found by us arises from the nuclear moment of copper; it only requires the presence of 3 parts in 10^7 of a strongly paramagnetic ion such as Fe^{++} to explain the remainder. Such an impurity content is reasonable for the particular copper used. Thus it seems plausible that the susceptibility of pure copper is substantially independent of temperature, in agreement with the simpler theories, and that the small temperature dependence which we observe results from paramagnetic impurities.

[1] de Haas and Van Alphen, Leiden Communs. 225b (1933).
[2] Bitter, Kaufmann, Starr, and Pan, Phys. Rev. **60**, 134 (1941).

N3. Effect of a Field on the Orthorhombic-Tetragonal Transition in Single Crystals of Barium Titanate. E. J. HUIBREGTSE AND D. R. YOUNG, *IBM Corporation.*—In $BaTiO_3$ the tetragonal to orthorhombic transition with zero bias occurs near 5°C, and the reverse transition at 11°C showing a hysteresis in temperature of ~6 degrees. A dc field applied in the direction of the tetragonal polarization lowers both transition temperatures. Fields of approximately 2.5 (10^4) volt/cm lower the orthorhombic to tetragonal transition below 5°C. Therefore, at temperatures slightly below 5°C, the crystal can be made to flip reversibly between the two states by varying the applied field. This effect has been observed in two ways; (1) measuring the dielectric constant *vs* field, and (2) the polarization (*z* component) *vs* field. The dielectric constant decreases abruptly by a factor of about 5 when the field becomes sufficient to change the polarization from the orthorhombic direction to the tetragonal. The tetragonal polarization, P_{zt}, is 25% larger than the orthohombic, P_{zo}, thus, when the hysteresis loop is observed at high fields, a triple loop results which is analogous to the double loop observed at the cubic-tetragonal transition. All transitions are sharp if the crystals are wholly electroded.

N4. Determination of Coefficients in Devonshire's Expansion for $BaTiO_3$ from Measurements on the Tetragonal-Orthorhombic Transition. D. R. YOUNG AND E. J. HUIBREGTSE, *IBM Corporation.*—The Devonshire expansion of the free energy, F, of $BaTiO_3$ in terms of the even powers of the polarization for the tetragonal and orthorhombic states can be written as follows:

$$F=A(P_x^2=P_z^2)+B(P_x^4+P_z^4)+C(P_x^6+P_z^6)+D(P_x^2P_z^2).$$

It is assumed that no domains have a component of P in the *y*-direction. From the measurements on the tetragonal to orthorhombic transition we have found it necessary to include an additional term of the form $G(P_x^2P_z^4+P_x^4P_z^2)$. The five coefficients evaluated for temperatures near the transition (~5°C) are obtained from the following information: (1) the extrapolation of the Curie-Weiss law; (2) the measured spontaneous polarization in both states; (3) the dielectric constant; and (4) by equating the free energy evaluated for each state at the midpoint of the temperature hysteresis. Results for the coefficients are (all in cgs units) $A=-3.7$ (10^{-5}), $B=-11.0$ (10^{-13}), $C=15(10^{-23})$, $D=2.8(10^{-13})$, and $G=9(10^{-23})$. A plot of P_s *vs* E_s calculated from the Devonshire expansion agrees qualitatively and quantitatively with the observed triple loops associated with this transition.

Post-Deadline Papers, If Any

WEDNESDAY MORNING AT 9:30

Grand Ballroom

(R. T. BIRGE presiding)

Invited Papers

NA1. Scattering of 40- to 130-Mev Photons by Protons and Other Nuclei. G. E. PUGH, *M.I.T.* (30 min.)

NA2. Compton Effect in Scattering of 100-Mev Gamma Rays by Protons. C. L. OXLEY, *University of Chicago.* (30 min.)

NA3. Scattering of High-Energy Electrons. R. HOFSTADTER, *Stanford University.* (30 min.)

NA4. Methods for Predicting Radioactive Fallout. G. L. FELT, *Los Alamos Scientific Laboratory.* (30 min.)

NA5. The Magneto-Ionic Expander Isotope Separator. J. SLEPIAN, *Westinghouse Research Laboratories.* (30 min.)

WEDNESDAY MORNING AT 9:30

Boston Room

(R. E. MARSHAK presiding)

Theoretical Physics, V

P1. Spin of the Σ Hyperon.* W. G. HOLLADAY, *University of Wisconsin and Vanderbilt University.*—The charged hyperons known as Σ particles are believed to have the decay schemes $\Sigma^- \rightarrow N+\pi^-$, $\Sigma^+ \rightarrow P+\pi^0$, and $\Sigma^+ \rightarrow N+\pi^+$ with $Q \sim 115$ Mev. From the branching ratio ($R_1 = \pi^0/\pi^+$) of the Σ^+ decay and the ratio R_2 of the Σ^+ to Σ^- lifetimes, it may be possible to decide whether the spin and parity of the Σ is $\frac{3}{2}+$. We assume that the Σ belongs to an isotopic spin triplet and that the final states are combinations of the $T=\frac{1}{2}$ and $T=\frac{3}{2}$ states. If the Σ has spin $\frac{3}{2}$ and even parity, then the final state has $l=1$, $J=\frac{3}{2}$. The $l=1$, $J=\frac{3}{2}$ resonance apparently existing in the pion-nucleon system in the $T=\frac{3}{2}$ state near 200 Mev would almost surely lead to an enhancement of the $T=\frac{3}{2}$ state over the $T=\frac{1}{2}$ in the final states of the Σ decay. R_1 would then be very nearly 2, and we might expect R_2 to be nearly unity. If the Σ is not a $\frac{3}{2}+$ particle, no resonance enhancement occurs; the simplest possibility then is that $R_1 \approx 1$ and $R_2 \approx \frac{1}{2}$.

* Supported in part by the Wisconsin Alumni Research Foundation.

P2. Radiative and Nonradiative Boson Decay into Leptons. SIDNEY A. BLUDMAN AND MALVIN A. RUDERMAN, *University of California, Berkeley.*—The decay $K_{\mu 2} \rightarrow \mu+\nu$, which is the commonest K-meson decay, is strikingly similar to $\pi \rightarrow \mu+\nu$. A simple phase-space estimate gives a $K-\mu$ lifetime less than one-tenth the $\pi-\mu$ lifetime, while the observed lifetimes are more nearly equal. In this note, we wish to point out that the long $K_{\mu 2}$ lifetime and the absence of K_{e2} are both understandable in terms of the same interaction (axial vector) as has been invoked to explain the absence of $\pi-e$ decay. Since this interaction is one that suppresses the emission of *fast* electrons, it had been expected[1] that radiative decays like $\pi \rightarrow e+\nu+\gamma$ might be relatively important. That this is not so, however, can be shown in a simple way by a generalized equivalence theorem. This work was supported in part by the U. S. Atomic Energy Commission.

[1] M. Ruderman, Phys. Rev. **85**, 157 (L) (1952).

P3. Higher-Order Corrections to the Nucleon-Nucleon Potential in Charge-Symmetric Pseudo-Scalar Theory.* JOHN M. GREENE† AND DAVID FELDMAN, *The University of Rochester.*—Sixth-order corrections to the potentials of Lévy-Klein and Brueckner-Watson have been examined in the adiabatic limit. These have been derived from the Foldy-Dyson transformed Hamiltonian by decoupling the Tamm-Dancoff amplitudes by means of canonical transformations; only those mesons that are interchanged between the nucleons have been taken into account. The two-pair and one-pair potentials have been expressed in analytical form; the no-pair term has been evaluated numerically. In general, the latter is smaller than the corresponding fourth-order no-pair potential for $\mu r > 0.6$ so that one cannot expect convergence of the weak-coupling expansion for the *ps–pv* potential for smaller distances. The sixth-order central force is repulsive in triplet-even states. This is also true when ladder-correction terms are omitted in the manner of Brueckner and Watson; the net result, for this case, is to yield an over-all potential which is weakly attractive at large distances and very strongly repulsive at small distances (with crossing point at $\mu r = 0.55$) so that previous agreement with experiment is nullified. Adiabatic and nonadiabatic corrections to the fourth- and sixth-order potentials will also be discussed.

* This research was supported in part by the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow.

P4. Certain Features of Pion Production in Two-Nucleon Collisions.* D. B. LICHTENBERG, *Indiana University.*—Use of the Chew-Low-Wick formulation of field theory leads to a particular form for the matrix elements of the various reactions involving pion production in nucleon-nucleon collisions.[1] These matrix elements are examined to see what qualitative information can be obtained about the cross sections. It is found that if the final two nucleons are emitted in a triplet state, tensor forces should not be neglected. The results are compared with the predictions of the phenomenological theory of Watson and Brueckner. The reaction $p+p \rightarrow \pi^+ + p + n$ is considered in greater detail.

* Work performed under a National Science Foundation contract.
[1] D. B. Lichtenberg, Phys. Rev. **100**, 303 (1955).

P5. An Interpretation of the π^-/π^+ Ratio in Photoproduction from Heavy Nuclei.* KIRK MCVOY, *Cornell University.*—A phenomenological investigation of the experimental results of Littauer and Walker[1] has been undertaken in an attempt to determine the specifically nuclear effects which cause the correlation between the π^-/π^+ ratio and $M_{Z-1} - M_{Z+1}$. Assuming that the presence of neighboring nucleons does not materially change the cross section,[2] the experimental cross section for production from free protons is averaged over a Fermi momentum distribution of nucleons, under the restrictions of energy and momentum conservation, and of the Pauli principle. In addition it is required that, in order to change the charge of a nucleon, a certain amount of potential energy be given up to the nucleus. This consists of the inverse beta-decay energy and an additional amount, V_0, which arises from positional correlations of the nucleons.[3] A comparison of the results of the calculation with the experiments will be presented.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] R. Littauer and D. Walker, Phys. Rev. **86**, 838 (1952).
[2] M. Lax and H. Feshbach, Phys. Rev. **81**, 189 (1951).
[3] G. Chew and J. Steinberger, Phys. Rev. **78**, 497 (1950).

P6. Determination of Scattering Parameters with Errors.* WILLIAM C. DAVIDON, *University of Chicago.*—The maximum likelihood and the least squares method have been used to analyze $\pi^+ + P$ and $P+P$ scattering experiments. Determinations have been made of phase shifts and of an expansion of cross sections in polynomials in cosine χ. In the maximum likelihood calculations, a procedure has been developed for hunting for the best solution in n-dimensions which converges more rapidly than the optimum gradient method or the customary variants of it. Several programs have been prepared for the AVIDAC computer which can be used for the analysis of $\pi^+ + P$ scattering in terms of phase shifts, and to expand any differential cross section in terms of Legendre polynomials in cosine χ. Programs have also been prepared for the evaluation of the error matrices for these parameters.

* Research supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

P7. Meson Production by Electrons. R. B. CURTIS, *University of Illinois.*—The meson energy and angle dependent differential cross section for the production of mesons by electrons has been calculated to first order in the fine structure constant. It is possible to split the transition probability into two terms, one of which is proportional to the photomeson differential cross section (the Williams-Weiszacker approximation), the other containing longitudinal current and other corrections. Experimental cross sections were used in the first term, and the correction term was calculated using the Chew-Low theory.* The cross section was calculated on the ILLIAC (the electronic digital computer at the University of Illinois) for electron energies from 200 Mev to 600 Mev, for meson energies at intervals of 25 Mev, and for meson angles of 0°, 90°, and 180° in the laboratory system. Results will be discussed.

* "Theory of photo-meson production at low energies" (to be published).

P8. Remark on Dirac Particles in a Central Field. N. N. KHURI AND A. S. WIGHTMAN, *Princeton University.*—Calculations for free Dirac particles of definite four momentum can be carried out easily using the Feynman "projection operator" $\frac{1}{2}(\mathfrak{p}+m)$. An analogous expression holds for a Dirac particle in a central field if $\mathfrak{p}$ is replaced by $\mathfrak{P}_{j,E}$ and m by $M_{j,E}$. Here $\mathbf{P}_{j,E}$ is a four component quantity bilinear in the Dirac momentum space radial wave functions and $\mathbf{P}_{j,E}^2 = M_{j,E}^2$. Therfore, all calculations of matrix elements and rates in central field problems are reduced to calculations formally equivalent with that in the free field case plus an integration over p. This operator was used to study the decay of a μ^- meson from a Bohr orbit. The square of the matrix element can be written down directly by looking at Michel's results[1] on the Fermi interaction between four free fermions. We only have to substitute the quantity $\mathbf{P}_{j,E}$ for the four-vector $\mathbf{p}$ and $M_{j,E}$ for m_μ. This result permits easier insight into previous work on μ^- decay in a Coulomb field.

[1] Louis Michel, thesis, Paris (1952), p. 69.

P9. Annihilation Products of the Antiproton. CHARLES J. GOEBEL, *University of California, Berkeley.*—Assume (a) annihilation takes place at small distances ($\approx M^{-1}$) and (b) the p–$\bar{p}$ force is qualitatively described by one-meson exchange. Then (a) implies low multiplicity and a strong centrifugal barrier effect. Absorption will be from S-states and annihilation will go into states containing a slow angular momenta as possible. Thus, the annihilation modes for given initial states are easily deduced; in some cases these include K-mesons. Assumption (b) implies a ranking of the four S-state p–$\bar{p}$ potential depths. But in hydrogen the electromagnetic cascade seems to fill all but one of the S-states, and MD to the lowest S-state can compete with direct annihilation only if the latter is inhibited by 10^{3-4} (e.g., by a nuclear force hard core). In nuclei, the annihilation products (except photons) will be in any case highly disguised. This work was performed under the auspices of the U. S. Atomic Energy Commission.

P10. Annihilation of Antiprotons. L. M. BROWN, I. HARRIS, AND M. PESHKIN, *Northwestern University.*—The $P^+ + P^- \rightarrow 2\gamma$ rate has been calculated using Dirac particles with Pauli anomalous moments. The cross sections agree under appropriate substitution with Powell's calculation of Compton scattering by protons.[1] In contrast to the latter, the annihilation rate is enhanced by a factor $A = 38$ in the nonrelativistic limit, where the total cross section is $A\pi(e^2/Mpc^2)^2(C/v)$. If antiprotons are stopped in hydrogen the protonic analog of positronium will be formed, and singlet S-states are forbidden to decay into two pions. Two pion decay would otherwise dominate at all energies[2] by roughly $(137)^2$. The probability of stopping depends on a close estimate of the mesonic annihilation cross section, requiring $\sigma < \pi R^2 C/(Sv)$, where R is the meson Compton wavelength. For stopped antiprotons, an appreciable number of the events either will be electromagnetic or will involve three or more pions. The three pion rate is unknown. Electron and muon pairs, assuming no anomalous muon moment, are less important than photons.

[1] John L. Powell, Phys. Rev. **75**, 32 (1949).
[2] Robert E. Marshak, *Meson Physics* (McGraw-Hill Book Company, Inc., New York, 1952), p. 341 *ff.*

WEDNESDAY AFTERNOON AT 2:00

Grand Ballroom

(E. T. BOOTH presiding)

Symposium on K-Mesons

Q1. Properties of Positive *K*-Mesons. R. W. BIRGE, *University of California, Berkeley.* (30 min.)
Q2. *K*-Meson Properties and Relative Abundances. D. RITSON, *M.I.T.* (30 min.)
Q3. Lifetimes of $K\pi 2$ and $K\mu 2$ Mesons. V. L. FITCH, *Princeton University.* (30 min.)
Q4. Spin and Lifetime of the Tau Meson. J. OREAR, *Columbia University.* (30 min.)

WEDNESDAY AFTERNOON AT 2:00

Manhattan Center, Gold Room

(W. L. BROWN presiding)

Semiconductors, II

QA1. Effect of Vacuum Treatments on Germanium Surface. GEORGE WALLIS AND SHYH WANG, *Sylvania Electric Products, Inc.*—Field effect[1] and photoresponse were used to study the effect of vacuum heat treatment on the germanium surface. From the measurements, information was obtained about carrier height, relative changes in surface recombination ve-

locity, and the surface state density, N_t. The sample was cut from p-type germanium (6.6 ohm-cm) with a lifetime of 40 μsec and etched with CP-4. After being exposed to a high-frequency discharge and to argon-ion bombardment,[2] the sample was annealed at 500°C in a vacuum of 10^{-7} mm Hg. Short heat treatments above 200°C produced a temporary reduction in surface recombination velocity. Evidence will be presented that the change was the result of a temporary reduction in N_t. Prolonged heating of the sample at 500°C produced a permanent reduction in N_t. Exposure to air approximately restored the initial N_t, indicating that gas ions may under certain conditions act as surface states.

[1] W. L. Brown, Phys. Rev. **98**, 1565 (1955).
[2] Farnsworth, Schlier, and Burger, Phys. Rev. **98**, 250 (1955).

QA2. Effects of Ion Bombardment Cleaning and of Oxygen Adsorption on Lifetime in Germanium.* H. H. MADDEN AND H. E. FARNSWORTH, *Brown University*.—Changes in mean lifetime due to adsorption of oxygen on the (100) face of a cleaned germanium single crystal have been obtained by observing the decay of photoconductivity.[1] The crystal was outgassed by prolonged heating (in excess of 100 hours) above 600°C in a high vacuum, and the surface was cleaned by argon ion bombardment.[2] A large decrease in mean lifetime was observed when the crystal was argon-ion bombarded. Long lifetimes were obtained again when the crystal was annealed at 500°C to 600°C in vacuum. Heating an ion-bombarded crystal in the presence of oxygen at a pressure of 3×10^{-7} mm Hg, however, produced a *decrease* in mean lifetime, showing that the foregoing increase on annealing in vacuum was not caused by residual oxygen. Adsorption of oxygen at a maximum pressure of 10^{-6} mm Hg on the crystal at room temperature, after ion bombardment and annealing in vacuum, produced no measurable changes in lifetime. Adsorption of oxygen, at a maximum pressure of 10^{-7} mm Hg, on the crystal at a temperature of about 100°C resulted in a small decrease in mean lifetime.

* Supported by the International Business Machines Corporation.
[1] D. T. Stevenson and R. J. Keys, J. Appl. Phys. **26**, 190 (1955).
[2] Farnsworth, Schlier, George, and Burger, J. Appl. Phys. **26**, 252 (1955).

QA3. Effects of Oxygen Adsorption on the Work Functions of Clean Germanium Surfaces.* J. A. DILLON, JR., *Brown University*.—The work function of the (100) face of a germanium single crystal (45 ohm-cm, 700 μsec, nearly intrinsic), following 150 hours of outgassing at 650°C in high vacuum and 2 hours of ion bombardment followed by annealing,[1] is 4.77 ev. That of the (111) face of a 10 ohm-cm, 60 μsec, n-type germanium sample is 4.79 ev. Adsorption of oxygen at room temperature and at a pressure of 2×10^{-7} mm Hg results in work function increases of 0.28 ev for the (100) face and 0.20 ev for the (111) face. There is no apparent desorption upon standing for long periods in high vacuum. The clean surface work function values can be restored by heating the samples in vacuum for 15 minutes at 500°C. The resistivities of the samples did not change appreciably during the experiments. Recent experiments with the (111) face of a somewhat imperfect germanium crystal (29 ohm-cm, p-type) suggest that the change in work function on exposure to oxygen increases when the crystal temperature is raised to a value between about 80°C and 200°C. At somewhat higher temperatures no change in work function is observed.

* Supported by a Joint Services Contract with the Massachusetts Institute of Technology and a subcontract with Brown University.
[1] Farnsworth, Schlier, George, and Burger, J. Appl. Phys. **26**, 252 (1955); J. A. Dillon, Jr., and H. E. Farnsworth, Phys. Rev. **99**, 1643 (1955).

QA4. Surface Structure and Oxygen Adsorption on the (100) Face of a Germanium Single Crystal, Using Low-Energy Electron Diffraction.* R. E. SCHLIER, *Brown University*.—The (100) face of a germanium single crystal has been re-examined by low-energy electron diffraction, using an apparatus greatly improved in resolution and accuracy. The data are obtained automatically and plotted on a recorder. These more complete data require a new interpretation. The electron diffraction beams from a cleaned surface (outgassed, argon ion bombarded, and annealed) are in accord with the assumption that the germanium atoms in the surface plane are displaced from their normal lattice positions. The rows of surface atoms in (110) directions are displaced by an undetermined amount in a direction parallel to the surface and perpendicular to the row. Each adjacent row is displaced in the direction opposite to that of its neighbor. The addition of a monolayer of oxygen to the surface produces a pattern which indicates that the germanium atoms are restored to their normal lattice positions, and that the oxygen atoms occupy positions close to the normal lattice positions of germanium atoms in the next layer above the surface. This oxygen layer is substantially complete after exposure to a pressure of 10^{-7} mm Hg for 25 min, at room temperature, and can be removed by heating to 500°C for 30 min.

* Supported by a joint services contract with the Massachusetts Institute of Technology and a subcontract with Brown University.

QA5. Field Effect in Germanium at High Frequencies. H. C. MONTGOMERY AND B. A. MCLEOD, *Bell Telephone Laboratories*.—Variations in field effect in a semiconductor with frequency are closely related to time constants of recombination centers and surface states. Small-signal field effect was measured in germanium at frequencies up to 5 Mc. The sample was one plate of a condenser, to which an ac voltage was applied. Resulting conductivity changes were detected by passing an ac current of the same frequency through the sample, and measuring the dc resulting from product modulation of the two signals.[1] The sign of the field effect at high frequencies always indicated majority carrier conduction. Some specimens had the opposite sign at low frequencies, indicating an inversion layer at the surface; in these the field effect changed sign at a frequency $\approx 1/$(minority carrier lifetime). Effective mobility deduced from the field effect at a megacycle was generally larger than at 100 cycles, sometimes nearly as large as bulk mobility, indicating that many of the "fast" surface states were in the range 10^{-3} to 10^{-7} second.

[1] P. Aigrain *et al.*, J. phys. radium **13**, 587 (1952).

QA6. Analysis of n-Type Germanium Magnetoresistance Data. COLMAN GOLDBERG, *Westinghouse Research Laboratories*.—The measured values[1] of the weak field magnetoresistance coefficients for 11 ohm-cm n-type germanium in the range from 77°K to 320°K agree with the model[2] which assumes that the energy surfaces are ellipsoids oriented along the (111) directions in k-space. Analysis of the data indicates that the mass ratio which describes the shape of the ellipsoids is approximately constant in this temperature range. The scattering mechanism, however, changes with temperature. The mass ratio is found to be approximately 12, and the scattering mechanism can be approximated by a relaxation time $\tau = l\epsilon^{-n}$, where n is temperature dependent varying continuously from 0.22 at 77°K to 0.45 at 250°K.

[1] R. E. Davis and C. Goldberg, Phys. Rev. **96**, 833 (1954).
[2] B. Abeles and S. Meiboom, Phys. Rev. **95**, 31 (1954).

QA7. Elastic Moduli of Indium Antimonide.* ROY F. POTTER, *National Bureau of Standards*.—The elastic moduli of p-type InSb have been measured as a function of temperature for the range 77°K to 673°K. We used the composite oscillator method, measuring the resonant frequency of both the longitudinal and torsional mode of a cylinder with its axis oriented in the 100 direction as well as the resonant frequency of longitudinal mode for a cylinder oriented in the 111 direction. The results are extrapolated to 0°K giving $C_{11}=6.75$, $C_{12}=3.47$, $C_{44}=3.16$. At 273°K the values are $C_{11}=6.48$, $C_{12}=3.27$, $C_{44}=3.09$, and at 673°K they are $C_{11}=5.38$, $C_{12}=2.69$, $C_{44}=2.95$. All are in units of 10^{11} dynes/cm^2. Using Sutton's[1] formula to evaluate the mean velocity

of sound at 0°K, we find $v_m = 2.26 \times 10^5$ cm/sec and $\theta_D = 205$°K. We used a value of 5.775 g/cm³ for the density of InSb at 25°C. Values for the coefficient of expansion will be given.

* Research supported by Office of Scientific Research, Air Research and Development Command.

[1] P. M. Sutton, Phys. Rev. **99**, 1826 (1955).

QA8. Thermomagnetic Effects in InSb.* R. K. WILLARDSON AND A. C. BEER, *Battelle Memorial Institute.*—Owing to the unusually high electron mobility in InSb, large galvanomagnetic effects have been observed. If temperature gradients exist across the specimen, one may expect correspondingly large thermomagnetic effects. Investigation of these phenomena is generally complicated by the fact that ordinary measurements are done under adiabatic conditions so that careful attention must be given to transverse gradients and the resulting additional second-order effects, since the region of interest encompasses values of $\mu H \gg 1$. However, by choosing boundary conditions such that transverse electric fields and temperature gradients are eliminated, both measurement and calculations are simplified. Under these conditions, it has been found that the contribution of the electrons to the thermoelectric power of intrinsic InSb at room temperature decreases significantly as the magnetic field is increased. Data were taken over a range of magnetic field strengths sufficient to change the thermoelectric power from -240 to $+75\ \mu V/$°C. Results are analyzed in terms of the electron and hole mobilities and the position of the Fermi level.

* This research was supported by the U. S. Air Force, through the Office of Scientific Research of the Air Research and Development Command.

QA9. Kinetics of Photoconductivity and Chemisorption in a Zinc-Oxide Semiconductor. D. B. MEDVED, *University of Pennsylvania** *and Convair.*—It is shown that the Elovich equation as applied by Melnick[1] to photoconductivity processes is the first term of a more general expression given by $at = \exp(\beta y) - 1 + 0(y^2)$ wherein y is the percentage of the photoconductivity decay from the saturation value and t the time of decay.[2] Deviations from expected behavior of results obtained with very thin specimens of sintered ZnO are ascribed to a monotonic decrease of conduction electron concentrations with increasing chemisorption. The fundamental rate limiting process in both the rise and decay of the photoconductivity is one in which conduction electrons penetrate the space-charge layer formed by ionized interstitial zinc atoms and chemisorbed gas on the surface. These electrons then interact with physically adsorbed gas atoms. For high signal levels, the photoconductivity decay is linear on log time basis over two decades approximately; a closer approximation to the predicted behavior is obtained by use of small signal light excitation where the percentage change in the conductance is usually less than 10%.

* Supported by U. S. Air Force Contract.

[1] D. A. Melnick, Ph.D. thesis, University of Pennsylvania (February, 1954).
[2] D. B. Medved, Ph.D. thesis, University of Pennsylvania (June, 1955).

QA10. Hall Effect and Conductivity of Transition Metal Diborides.* H. J. JURETSCHKE, *Polytechnic Institute of Brooklyn,* AND R. STEINITZ, *American Electro Metal Corporation.*—Room temperature electrical properties of all of the isomorphic metallic compounds MB_2, with M a transition metal in group IV, V, or VI, have been determined on pressed and sintered samples. Bulk values reported below are obtained after porosity corrections. Resistivities lie between 7 and 40 micro-ohm-cm, increasing regularly from the fourth to the sixth group. All Hall constants are negative, in contrast to those of the parent metals. For M in group V or VI, the Hall constants are of order 10^{-12} v cm/amp gauss. For M=Ti, Zr, Hf, they are 20 times as great, indicating that the Fermi level is near a band edge for M in group IV. Hall measurements on solid solutions of these compounds show that the addition of higher group diborides to those of the fourth group leads to a proportional increase in the carrier density, such that the compounds of group V have very close to one conduction electron per metal atom. The main conduction band overlaps slightly the next lower band.

* Supported in part by the Office of Naval Research.

QA11. Rectification at the Junction between Crystals of *p*- and *n*-type Silicon Carbide. I. R. ALLEN SHUTTLEWORTH AND B. C. BRADSHAW, *Signal Corps Engineering Laboratories.*—We have demonstrated that *p-n* junctions made by pressing together crystals of *p*-type and of *n*-type silicon carbide rectify an alternating current when there is an interfacial resistance, and that when the latter is broken down by high-voltage discharge across the contact the current is no longer rectified. The rectification is without exception restored simultaneously with the interfacial resistance either by sliding or by separating and rejoining the crystals, and the entire process can be repeated indefinitely with the same crystal pair. The behavior of the junctions is independent of whether the high-resistant film is adsorbed air or, for example, ambroid cement. The thermojunction potential remains constant throughout. Rectification factors are of the order of 10^4.

QA12. Rectification at the Junction between Crystals of *p*- and *n*-type Silicon Carbide. II. B. C. BRADSHAW AND R. ALLEN SHUTTLEWORTH, *Signal Corps Engineering Laboratories.*—The action of the high-resistant interfacial layer in the rectification just described is explained as follows: when a potential is applied in the forward direction, the holes and electrons approach each other and the barrier layer, the resistivity of which is about 10^7 times as great as that of the crystals; the electrical barrier height, about one volt, is exceeded, and the barrier layer acts as a conventional resistance in series with the line. When the potential is applied in the reverse direction, the barrier height is not exceeded because as soon as a small potential builds up across the resistant layer the holes and electrons begin to move away from it; thus the barrier layer thickens, and the field remains small. Consequently, those electrons which cross the resistant layer do so by tunneling. If the resistant layer is absent electrons and holes cross the *p-n* interface freely in either direction, and there is no rectification. Order-of-magnitude agreement is found between theory and experiment.

WEDNESDAY AFTERNOON AT 2:00

Panel Room

(W. W. HAVENS, JR., presiding)

Neutron Physics, I

R1. Elastic Neutron Scattering by Li^7 as a Polarization Analyzer. H. B. WILLARD, J. K. BAIR, H. O. COHN, AND J. D. KINGTON, *Oak Ridge National Laboratory.*—Neutrons elastically scattered by Li^7 have a strong p-wave ($J = 3^+$) resonance at 256-kev incident energy.[1] The interference with the s-wave potential scattering background should give rise to fairly

large polarizations, thus making it a useful analyzer. Neutrons emitted from the $Li^7(p,n)Be^7$ reaction at $\bar{E}_{p\ lab}=2.2$ Mev, $\theta_{1\ lab}=70°$ (φ_1 cm $=90°$) $\bar{E}_{n\ lab}=280$ kev were scattered from a Li^7 sample 1 in. in diameter 4 in. long through angles of $\theta_{2\ lab}=\pm 49°$ (φ_2 cm $=\pm 55°$) and $\theta_{2\ lab}=\pm 82°$ (φ_2 cm $=\pm 90°$) by a technique previously described.[2] Energy resolution was 14 kev. The averaged values of the product polarizations obtained from measured asymmetry ratios, corrected for multiple scattering were $P_1(90°)\ P_2(55°)=-0.20\pm 0.04$ and $P_1(90°)\ P_2(90°)=-0.27\pm 0.05$, respectively. Assuming that the *s*-wave potential scattering channel spins are statistically mixed,[3] the calculated polarization values for elastic neutron scattering by Li^7 through cm angles of 55° and 90° at $E_{n\ lab}=280$ kev are $P_2(55°)=-0.34$ and $P_2(90°)=-0.37$. This gives an average value for $P_1(90°)=0.66\pm 0.09$. If the *s*-wave potential scattering is all channel spin 2,[4] the average value becomes $P_2(90°)=0.59\pm 0.08$.

[1] P. H. Stelson and W. M. Preston, Phys. Rev. **84**, 162 (1951).
[2] Willard, Bair, and Kington, Phys. Rev. **95**, 1359 (1954).
[3] Willard, Bair, Kington, and Cohn, Phys. Rev. (to be published).
[4] Thomas, Walt, Walton, and Allen, Phys. Rev. (to be published).

R2. Elastic Scattering of 3.7 Mev Neutrons from Zirconium.† H. S. HANS* AND S. C. SNOWDON, *Bartol Research Foundation.*—The differential cross section for 3.7-Mev neutrons elastically scattered from zirconium has been measured for fifteen angles between 25° and 145° using a ring geometry. The measurements have been carried out using both the ZnS-Lucite scintillating detector[1] and the scintillating plastic sphere detector.[2] The resulting measurements have been corrected for the energy discrimination curve of the detector, the angular sensitivity of the detector, and the angular resolution effects owing to the finite size of scatterer and detector. A Monte Carlo type calculation[3] is under way at present in order to remove the multiple scattering contributions from the scattering. The results compare favorably with those previously obtained at 4.1 Mev by Walt and Beyster.[4]

† Assisted by the U. S. Atomic Energy Commission.
* Fulbright Fellow from Muslim University of Aligarh, India.
[1] W. F. Hornyak, Rev. Sci. Instr. **23**, 264 (1952).
[2] McCrary, Taylor, and Bonner, Phys. Rev. **94**, 808(A) (1954).
[3] These calculations are being undertaken by Dr. R. Jastrow at the Naval Research Laboratory.
[4] M. Walt and J. R. Beyster, Phys. Rev. **98**, 677 (1955).

R3. Neutron Resonance Scattering at 180° and 90°.* R. C. BLOCK† AND HENRY W. NEWSON, *Duke University.*—The 90° and 180° neutron differential scattering cross sections of F, Na, Mg, Al, K, Cr, V, and Bi have been measured in the energy range, 30 kev to 110 kev. Applying the analysis of Blatt and Biedenharn,[1] to the observed resonances, the following level assignments have been made:

Target nucleus	E_0(kev)	l	$J\pi$
F^{19}	28	1	$1^-,2^-$
F^{19}	50,99	1	1^-
Na^{23}	53	1	$3^-,(2^-)$
Mg^{24}	85	1	$3/2^-$
Al^{27}	90	0,(1)	$3\pm(3^\pm)$
Cr^{52}	58,100	0	$1/2^+$

where the quantities in parentheses are possible, but less likely, assignments. The assignments are well in accord with those obtained from total cross sections.[2] Some information on channel spin has also been obtained.

* Work supported by the U. S. Atomic Energy Commission.
† Now at Oak Ridge National Laboratory.
[1] Blatt and Beidenharn, Revs. Modern Phys. **24**, 258 (1952).
[2] BNL, 325; also unpublished assignments.

R4. Energy Distribution of Cold Neutrons Scattered from a Single Crystal of Aluminum.* R. S. CARTER, H. R. MUETHER, D. J. HUGHES, AND H. PALEVSKY, *Brookhaven National Laboratory.*—The lattice vibrations of aluminum have been studied by analyzing the energy distribution of very low energy neutrons scattered inelastically by a single crystal of aluminum. By measuring the change in the wave vector and energy of the incident neutrons, it is possible to determine the wave vector and energy of the elastic wave with which the neutrons interacted. By varying the experimental conditions, it is possible to study many elastic waves and thereby determine the dispersion law for the lattice vibrations in the crystal. Because the neutron inelastic cross sections are very small the neutron beam must be intense. We have obtained a high intensity, very low energy beam by filtering a pile beam of neutrons through an eight-inch beryllium filter giving a beam of neutrons of energy less than 0.004 ev. The energy distribution of the scattered neutrons is measured by chopping the beam mechanically and measuring the neutron time of flight over a known path length. Discrete peaks are observed in the energy distribution corresponding to specific elastic waves. The energy of the peak compared to the energy of the incident neutrons gives the wave vector and energy of the specific elastic wave.

* Work performed under contract with U. S. Atomic Energy Commission.

R5. Scattering of 4.4-Mev Neutrons by Cr and Mo, and of 6.5-Mev Neutrons by Fe.* J. B. WEDDELL AND B. JENNINGS, *Westinghouse Research Laboratories.*—The spectra of neutrons scattered at 90° by chromium and molybdenum have been measured, for 4.4-Mev incident neutrons, by the proton recoil nuclear emulsion technique.[1] A similar measurement was made for iron at 6.5 Mev. Existence of energy levels in Cr^{52} at 1.46, 2.40, and 3.13 Mev was confirmed.[2] A spectrum of neutrons inelastically scattered by Mo was observed, but no single group was resolvable. Elastically scattered neutrons were observed from both Cr and Mo. The interaction of 6.5-Mev neutrons with Fe is markedly different from that of 4.4-Mev neutrons,[1] with much less elastic scattering at 6.5 Mev. The lower states of Fe^{56} are more weakly excited by 6.5-Mev neutrons. The density and strength of the higher excited states are sufficiently great to permit application of the evaporation model.[3] Values of the elastic and inelastic differential scattering cross sections will be presented and compared to theoretical predictions.

* Supported in part by the joint programs of the ONR and AEC.
[1] Jennings, Weddell, Alexeff, and Hellens, Phys. Rev. **98**, 582 (1955).
[2] W. C. Peacock and M. Deutsch, Phys. Rev. **69**, 306 (1946); R. M. Kiehn and C. Goodman, Phys. Rev. **95**, 989 (1954).
[3] E. R. Graves and L. Rosen, Phys. Rev. **89**, 343 (1953).

R6. Scattering of 4.4-Mev Neutrons Using a Time-of-Flight Technique.* R. V. SMITH, *Westinghouse Research Laboratories.*—4.4-Mev neutrons from the *d-d* reaction were produced in 1 mμsec pulses by sine wave chopping of the 15 μa beam from the Westinghouse electrostatic generator. The spectra of neutrons scattered through 90° by various scatterers were obtained from the time delay between the output pulses of two photomultipliers, one viewing light pulses produced inside the deuterium gas target by the deuteron pulse, and the other viewing a plastic scintillator placed 60–100 cm from the scatterer inside a large paraffin-boron-lead collimator. The two photomultiplier pulses were displayed on the same linear oscilloscope sweep and recorded photographically. Preliminary data will be presented for iron, zirconium, and carbon, showing neutron groups corresponding to elastic and inelastic scattering up to 3-Mev excitation and the de-excitation γ rays. These results show an over-all time resolution of 2–3 mμsec, limited largely by photomultiplier transit time spread, and a background due mostly to air scattering and collimator penetration. The effects of various shielding geometries and of various factors contributing to the time resolution will be discussed.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

R7. Inelastic Scattering of Neutrons by Na^{23}.† H. HAUSMAN,* J. E. MONAHAN, F. P. MOORING, AND S. RABOY, *Argonne National Laboratory.*—A measurement of the inelastic cross section of Na^{23} for neutrons in the energy range 440 kev to 700 kev has been carried out by comparing the yield of the 440-kev γ rays from Na^{23} (n,n') with that of the 478-kev γ rays from $B^{10}(n,\alpha)Li^{7*}$.[1] Resonances were observed at neutron energies of 542, 602, 633, and 710 kev. The results of these measurements, together with those of Stelson and Preston,[2] are consistent with the spin assignment 5/2+ for the 440-kev level in Na^{23}.

† Performed under the auspices of the U. S. Atomic Energy Commission.
* The Ohio State University.
[1] Petree, Johnson, and Miller, Phys. Rev. **83**, 1148 (1951).
[2] P. H. Stelson and W. M. Preston, Phys. Rev. **88**, 1354 (1952).

R8. Inelastic Scattering of 14-Mev Neutrons Measured by Time-of-Flight.* HARVEY CASSON, *Argonne National Laboratory.*—Energies of inelastically scattered neutrons produced by 14-Mev neutrons of the $T(d,n)\alpha$ reaction can be measured by a fast coincidence circuit time-of-flight method. Using a millimicrosecond coincidence circuit to detect coincidences between the alpha particles and the scattered neutrons, the coincidence rate is determined as a function of the distance between the scatterer and the Zr-T target. Peaks in the coincidence curve indicate the presence of inelastic neutron groups. Using a carbon scatterer, an inelastic group, consistent with the excitation of the 4.4-Mev level of C^{12}, is observed. Results on carbon and other elements will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

R9. Nuclear Excitation by Inelastic Neutron Scattering.* R. B. DAY, *Los Alamos Scientific Laboratory,* AND A. E. JOHNSRUD AND D. A. LIND, *University of Wisconsin.*—Gamma rays from excitation by inelastic neutron scattering of a number of elements have been observed. Tentative energy assignments are as follows: Zr; 0.51, 0.56, 0.91, 1.42, 2.17, and 3.29 Mev. Pb^{206}; 0.53, 0.80, and 1.72 Mev. In; 0.26, 0.50, 0.91, 1.11, and 1.42 Mev. Si; 1.28, 1.79, and 2.19 Mev. B; 0.73 and 2.14 Mev. Sc; 0.36, 0.53, 0.72, 0.97, 1.23, and 1.41 Mev. Ta; 0.14, 0.16, 0.21, 0.35, 0.48, and 0.62 Mev. Au; 0.20, 0.28, and 0.50 Mev. Tl; 0.20, 0.28, 0.40, 0.44, 0.62, and 0.70 Mev. Rings of the target material were bombarded by neutrons having energies in the range 0.35 to 3.9 Mev, produced in the $H^3(p,n)$ reaction at the large Los Alamos electrostatic generator. The gamma rays were detected by a 1 in. ×1 in. NaI detector shielded from the direct neutron beam, and the pulses were analyzed with the Los Alamos 100-channel analyzer. In Zr the 0.51 line has a threshold at $E=1.75$ Mev and is interpreted as annihilation radiation from internal pairs formed in the decay of O^+ first excited state of Zr^{90}. The 0.53-Mev line of Pb^{206} has an excitation threshold of 1.4 Mev. The excitation functions for a number of lines corresponding to transitions between known spin states in these nuclei will be analyzed on the basis of the statistical model.

* This work was carried out at the Los Alamos Scientific Laboratory and supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.

R10. Inelastic Scattering of 2.45-Mev Neutrons.* LAWRENCE CRANBERG AND JULES S. LEVIN, *Los Alamos Scientific Laboratory.*—Using a time-of-flight apparatus in conjunction with an electrostatic accelerator whose output is pulsed,[1] a survey has been made of the spectra of inelastic scattering from many elements at 90°, for a primary neutron energy of 2.45 Mev. In addition, detailed measurements of the spectra have been made as a function of scattering angle for iron, nickel, and titanium. These measurements give the angular distribution of the elastically scattered neutrons and of the inelastically scattered neutrons corresponding to the most strongly excited levels of the target neclei. The angular distributions of the gamma rays accompanying de-excitation of these levels are also obtained. Cross sections are obtained by comparison with the differential n–p scattering cross section. The inelastically scattered neutrons show a small but statistically significant anisotropy. For the case of the 850-kev level in iron the neutron yield at 160° is 83% of that at 90°, compared to the 95% predicted by the Hauser-Feshbach[2] theory.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] L. Cranberg, paper P/577, Proceedings of the International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland (August, 1955).
[2] W. Hauser and H. Feshbach, Phys. Rev. **87**, 366 (1955); Calculations by W. S. Emmerich, Westinghouse Research Laboratory (private communication).

R11. Cloudy Crystal Ball Analysis of Neutron Scattering Data. H. MCMANUS, *Chalk River Laboratories.*—Calculations made on a cloudy crystal ball model with a diffuse edge, using various values of edge thickness and strength of the imaginary part of the potential, have been compared with the differential elastic cross section for bismuth with 14.6-Mev neutrons measured by Cross and Jarvis.[1] The variation of the total and absorption cross sections with neutron energy has also been calculated in the region 4 to 14 Mev.

[1] W. G. Cross and R. G. Jarvis, Phys. Rev. **99**, 621 (A) (1955).

R12. Large-Angle Scattering of 14-Mev Neutrons from Lead.* H. A. MEHLHORN,† *Brown University.*—Differential cross section for elastic scattering of 13.5 Mev neutrons from lead has been measured at 10° intervals from 90° to 150°. Neutron detection and energy discrimination for identification of elastic scattering was accomplished with Ilford C2, 400μ nuclear emulsion plates. No increase in differential elastic cross section with increasing angle above 130° such as has been observed at lower energies[1,2] is found. With the exception of a pronounced dip and rise between 110° and 130°, also observed for 4.1-Mev neutrons,[3] the differential elastic scattering cross section falls steadily with increasing scattering angle. Investigation of the total scattering at 90°, 110°, 130°, and 150° also indicates a steady decrease with increasing scattering angle.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at Schlumberger Instrument Company, Ridgefield, Connecticut.
[1] S. Yamabe and J. Sanada, J. Phys. Soc. (Japan) **7**, 136 (1952).
[2] W. D. Whitehead and S. C. Snowdon, Phys. Rev. **92**, 114 (1953).
[3] M. Walt and J. R. Beyster, Phys. Rev. **98**, 677 (1955).

WEDNESDAY AFTERNOON AT 2:00

Terrace Room

(E. P. WIGNER presiding)

Invited Papers

RA1. On the Use of Digital Computers. P. M. MORSE, *M.I.T.* (30 min.)

RA2. Research Instrumentation Using Digital Computing Circuitry. H. L. SCHULTZ, *Yale University.* (30 min.)

RA3. Survey of Quantum Electrodynamics. W. PAULI, *Eidgenössische Technische Hochschule, Zurich.* (45 min.)

WEDNESDAY AFTERNOON AT 2:00

Boston Room

(H. A. BOORSE presiding)

Cryogenics

Invited Paper

S1. Effects of High Pressure on Superconducting Transitions and on the Electrical Conductivity of Metals at Low Temperatures. JOSEPH HATTON, *Harvard University.* (30 min.)

Contributed Papers

S2. Film Flow from a Rotating Beaker of Helium II.* R. J. DONNELLY AND R. H. WALMSLEY,† *Yale University.*—A cylindrical beaker containing helium II was rotated about its principal axis at peripheral speeds ranging from 10 to 60 cm/sec. The ratio of creep rate during rotation to creep rate in the stationary case was measured during each trial by noting the rate of fall of the meniscus with the motor drive alternately off and on. No change in flow rate was observed for peripheral speeds up to 20 cm/sec. At higher speeds the rate of loss of liquid increased by as much as 35% at 60 cm/sec. It is difficult to interpret the increase as due to any mechanism other than film flow, since the same increase was observed in a beaker fitted with a ground glass plug. Other precautions included the use of a heavy copper radiation shield and an actual measurement of the temperature in the rotating beaker. The effect of presence of contamination will be discussed.

* Assisted by the Office of Ordnance Research.
† Danforth Fellow.

S3. Comments on Bohm's New Theory of Superfluid Helium II.* GEORGE J. YEVICK† AND JEROME K. PERCUS, *Stevens Institute of Technology.*—In a very interesting quasi-phenomenological theory based on second quantized wave functions for the N-body Einstein-Bose system, Bohm explains the essential features of the superfluid properties of helium II. Writing $\psi = R \exp iS/\hbar$, the "quantum-mechanical potential" explicitly appears; the remaining potential is phenomenologically approximated by a compression term. The classical (many quantum) limit yields at once the critical velocity for capillary flow. Bohm carries out second quantization of the quantum fluid by expanding about the classical solution. Thereby he obtains an energy spectrum which for low wave number is linear in k (phonon region) and then goes over into "particle-like" k^2 dependence. In our theory[1] using collective coordinates, we obtain an analogous dependence on the wave number but with the transition region into the particle-like behavior depending explicitly on the interaction potential and the temperature. Furthermore the quantum mechanical potential is a direct consequence of the nonorthogonality of the transformation into collective coordinates, and for large wave number dominates the spectrum.

* Supported in part by the Office of Naval Research.
† We are greatly indebted to Professor Bohm for detailed discussions pertaining to his theory.
[1] George J. Yevick and Jerome K. Percus, Phys. Ref. **98**, 1164(A) (1955).

S4. Thermal Gradient in Helium II.* JOHN REPPY AND C. A. REYNOLDS, *University of Connecticut.*—Carbon thermometers were buried in a length of packed rouge into which helium was condensed. A heater was buried at one end of the column and a thermometer was placed at the other end, beyond the rouge. The system was a closed one; thermal contact was made with the helium bath through a copper sleeve at the end of the rouge column. The average rouge channel radius was 0.1 micron; the effective total cross section 2.8 cm²; and the distances of the buried thermometers from the cold reservoir thermometer were 2.8, 6.5, and 8.1 cm. Except for uncertainties at very low powers the temperature differences varied linearly with power in the range used. In addition the temperature differences were nearly, if not exactly, proportional to length. This justifies an assumption made in a previous work.[1]

* Supported in part by the Office of Naval Research and a grant from the Sigma Xi-RESA Research Fund.
[1] H. Forstat and C. A. Reynolds, Phys. Rev. (to be published).

S5. Ultrasonic Velocity in Superconducting Tin. H. E. BÖMMEL AND H. J. MCSKIMIN, *Bell Telephone Laboratories.*—Measurements were made to detect a *change* in the velocity v of longitudinal waves between the normal and superconducting state of a single crystal of tin at a frequency of 60 Mc/sec. The apparatus used was an ultrasonic interferometer designed and built by H. J. McSkimin which compared the phases of two ultrasonic channels, one containing the tin sample, the other containing a variable mercury delay line. The sensitivity was such that changes of v in the order of about 1.2 parts in 10^7 could be detected. An increase of about 3 to 4 parts in 10^7 was observed at 3.68°K when superconductivity was destroyed by a magnetic field. The change was slightly higher at 1.6°K. This is the order of magnitude one could expect from thermodynamic considerations.[1] The much larger changes reported by Landauer[2] and Welber[3] at 50 kc/sec are not yet fully explained.

[1] D. Shoenberg, *Superconductivity* (Cambridge University Press, Cambridge, 1952), p. 74.
[2] J. K. Landauer, Phys. Rev. **96**, 296 (1954).
[3] B. Welber, Bull. Am. Phys. Soc. **30**, No. 1, 57, (1955); Paper K4, 49th meeting Acoustical Society of America, (1955).

S6. Measurement of the Wiedemann-Franz Ratio at Low Temperatures.* W. J. SHATTES† AND B. SERIN, *Rutgers University.*—The method of Kohlrausch[1] for determining the Wiedemann-Franz ratio has been adapted for measurements in the temperature range provided by liquid helium. The metal specimen, in the form of a long wire, has its two ends in thermal contact with the helium bath. The remainder of the specimen is enclosed in a vacuum calorimeter. A temperature difference, ΔT, is established between the center and the ends of the wire by sending a current through it. ΔT is measured with carbon resistance thermometers, and the potential drop, V, across the wire is also determined. The Wiedemann-Franz ratio equals $V^2/8\Delta T$. Measurements on silver yield a value for the Lorentz number of 2.43×10^{-8} (V/deg)² in good agreement with the theoretical value of 2.44×10^{-8}. This method is convenient for measurements on specimens whose thermal conductivity does not exceed about 1 w/cm deg; it is much more flexible than the modification of the Kohlrausch method used by Chentsov.[2]

* Supported by the Office of Naval Research and the Rutgers Research Council.
† Present address: Tung Sol Electric Inc., Bloomfield, New Jersey.
[1] See: H. S. Carslaw, *Mathematical Theory of the Conduction of Heat in Solids* (Dover Publications, New York, 1945), p. 81 ff.
[2] R. A. Chentsov, Zhur.Eksptl. Teort. Fiz. **27**, 126 (1954).

S7. Effect of Superconducting Transition on the Rectification at a Semiconductor: Superconductor Contact. G. GROETZINGER, J. SCHNEIDER, AND P. SCHWED, *N.A.C.A.*—A rectifying contact was formed by vacuum deposition of a layer of tin approximately 0.001 in. thick and $\frac{1}{16}$ in. in diameter on a piece of *n*-type germanium. The Ge had been doped with As and Ga so as to retain approximately $\frac{1}{3}$ its room temperature conductivity at liquid helium temperatures. The system was brought to 3.6°K and the current at a number of fixed voltages was observed with the Sn alternately in the superconducting and the normal state, the latter being achieved by applying a magnetic field of 600 gauss. It was found that the current in the forward direction (Ge negative relative to Sn) was greater when the Sn was superconducting. In a typical case the maximum relative change in this current amounted to 0.8% and occurred at an applied voltage of 3.8 v and a current of 0.03 amp. For higher currents both the relative and absolute size of the effect decrease rapidly. A simple consideration shows that the disappearance of the resistance of the Sn when it becomes superconducting is not responsible for the observed effect.

S8. Transverse Lattice Oscillation Electron Interaction in Superconductivity. M. DRESDEN, *University of Kansas.*—It is well known that the Hamiltonian of the Fröhlich theory, contains several approximations, all depending for their validity on the smallness of certain terms in the electron-phonon interaction. Among others, one usually neglects the interaction between transverse lattice waves and the electrons. In general this is most likely a legitimate approximation; it must be stressed however that the energies involved in the superconductive transition are minute, so that conclusions about the reliability of the omission of terms are likely to be tenuous. It was shown by Schafroth[1] that the Fröhlich Hamiltonian, in perturbation approximation in any case, does not lead to the London equations. A calculation similar to the one performed by Schafroth was made, to investigate whether the inclusion of transverse lattice oscillation electron interaction terms in the Hamiltonian would alter this conclusion. If one makes a development of the density matrix, which is in fact a perturbation type procedure, one obtains again the Schafroth result. Preliminary calculations indicate that if one includes the Peierls processes in the description of the electron phonon interactions one obtains definitely modified results.

[1] M. R. Schafroth, Helv. Phys. Acta **24**, 645 (1955).

S9. Theory of Spectra of Atoms and Molecules in Solid Nitrogen Condensed at 4.2°K.* C. M. HERZFELD, *National Bureau of Standards.*—The observed emission spectra[1] of solids condensed at 4.2°K from electric discharges through nitrogen are explained by assuming that large numbers of atoms in various excited states are deposited in the process. Approximate calculations show that one set of emission lines corresponds to the forbidden $^2D \rightarrow {}^4S$ transition in N atoms, which is perturbed by crystal field effects. Band emission spectra are obtained which arise when atoms combine to form molecules in highly excited states. The most intense band system is analyzed, and arises from the $^5\Sigma \rightarrow A\,^3\Sigma$ transition. The analysis provides values of $D_0(=1060\ \text{cm}^{-1})$, and r_0 (approximately 1.5 A), for $^5\Sigma$, and a lower limit of 9.632 ev for the heat of dissociation of the ground state of N_2. Several effects of the crystal field on the molecular levels are observed.

* This research was supported by the U. S. Air Force, through the Office of Scientific Research of the Air Research and Development Command.

[1] A. Bass and H. P. Broida, J. Opt. Soc. Am. **44**, 905 (1955); H. P. Broida and J. R. Pellam, Phys. Rev. **95**, 845 (1954).

S10. Oscillatory Galvanomagnetic Properties of Bismuth Single Crystals in Longitudinal Magnetic Fields. JULIUS BABISKIN, *U. S. Naval Research Laboratory and Catholic University of America.*—Galvanomagnetic effects have been observed for oriented bismuth single crystals at liquid helium temperatures in longitudinal magnetic fields (H_L) up to 60 000 gauss. For the two crystal orientations studied, both the magnetic field and measuring current were either (1) parallel to the trigonal axis or (2) perpendicular to the trigonal axis and parallel to a binary axis. The observed longitudinal and transverse voltage sin H_L were $10^{-3}-10^{-5}$ times the corresponding galvanomagnetic effects (i.e. magnetoresistance and Hall effect) in transverse magnetic field (H_T). In addition, each crystal exhibited galvanomagnetic oscillations of the de Haas-van Alphen type[1] in H_L. The periods of these oscillations are the same as those observed for galvanomagnetic effects in H_T using the same orientations between the magnetic field and the crystalline axes. Therefore, the periods of galvanomagnetic oscillations are unaffected by current direction within experimental limits. For the second crystal orientation, the longitudinal voltage exhibited (1) a maximum similar to that observed in antimony[2] and (2) oscillations of short period at high fields which agree roughly with calculated de Haas-van Alphen oscillations.[1]

[1] D. Schoenberg, Trans. Roy. Soc. (London) **A245**, 1 (1952).
[2] M. C. Steele, Phys. Rev. **97**, 1720 (1955).

WEDNESDAY EVENING AT 7:30

Grand Ballroom

(FREDERICK SEITZ presiding)

Banquet of the American Institute of Physics and of Its Founder Societies

AFTER-DINNER SPEECHES

International Cooperation in Science. I. I. RABI.

Reef Creatures: the Great Barrier Reef of Australia (illustrated with movies). JEROME SCHWEITZER.

THURSDAY MORNING AT 9:30

Manhattan Center

(E. P. WIGNER presiding)

Joint Ceremonial Session of APS and AAPT

Retiring Presidential Address of the American Physical Society

T1. Physics and Physicists of the Past Half-Century. R. T. BIRGE, *University of California, Berkeley.*

(R. R. PALMER presiding)

Fourteenth Richtmyer Memorial Lecture of the AAPT

T2. The Development of Concepts in Semiconductor Research. W. H. BRATTAIN, *Bell Telephone Laboratories.*

Presentation of the Oersted Medal of the AAPT

Response by the Oersted Medallist

T3. Physics in Leiden in the Middle Twenties; Reminiscences of Professor Paul Ehrenfest. G. UHLENBECK, *University of Michigan.*

THURSDAY AFTERNOON AT 2:00

Manhattan Center

(FREDERICK SEITZ presiding)

Addresses in Honor of the Twenty-Fifth Anniversary of the American Institute of Physics
"Anticipations"

TA1. J. A. STRATTON, *M.I.T.*
TA2. H. G. B. CASIMIR, *Philips Research Laboratories, Eindhoven.*
TA3. J. R. OPPENHEIMER, *Institute for Advanced Study.*

FRIDAY MORNING AT 9:30

Grand Ballroom

(M. S. LIVINGSTON presiding)

Accelerators

U1. Cornell Alternating Gradient Synchrotron. I. Magnet.* A. SILVERMAN, D. CORSON, J. DEWIRE, D. LUCKEY, R. MARTIN, B. MCDANIEL, R. WILSON, AND W. WOODWARD, *Cornell University.*—The guide field for the Cornell electron synchrotron is provided by a 30-cps C-shaped magnet. The *c*'s are punched from laminations of dimensions 0.014 in. ×15 in. ×15 in. The total weight of the magnet is 25 tons; the power consumption 100 kw at 1-Bev excitation. The pole pieces are designed so that they can be restacked without disturbing the *c*'s or exciting coils. The magnet is divided into four quadrants of radius 150 in. at the orbit with 3-ft gaps between quadrants. Lenses, with n value of 21.2, corresponding to a field gradient of 5% per centimeter, are stacked symmetrically such that each half-quadrant has the arrangement, length L of negative n, $(dH/dr>0)$, length $2L$ of positive n, and length L of negative n. In the center of each quadrant is a zero gradient section of 3-ft length. The magnet is operated with dc bias. The ratio of ac to dc can be varied to produce any desired slope at injection time. Various systems of coils are employed to correct the field at injection time. Comparison with conventional synchrotrons will be made.

* Work supported by joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

U2. Cornell Alternating Gradient Synchrotorn. II. Operation.* B. MCDANIEL, D. CORSON, J. DEWIRE, D. LUCKEY, R. MARTIN, A. SILVERMAN, R. WILSON, AND W. WOODWARD, *Cornell University.*—The magnet described above is biased off by about 95% of the ac current. The dc is stabilized to a

fixed value and the ac is stabilized to give correct slope at injection time. Electrons are injected from a 2-Mev Van DeGraaff along an outer radius. Pulse currents of 100 ma, adjustable in duration from 0.05 to 1 μsec are obtained. Deflection and focusing controls introduce the beam through a 45° electrostatic inflector into a glass donut of 1 in.×3 in. cross section. During the first 15 Mev of acceleration, rf is supplied by a 2% frequency modulated cavity at 5 kv. A fixed frequency cavity operating at 86.7 mc and 25 kv completes the acceleration. Transfer is effected without appreciable loss of beam. Alignment is made by setting inflector on equilibrium orbit. Correction coils are adjusted to make the beam follow the central orbit. Inflector is then moved out and successive turns are tuned up. A tungsten rod, rotated synchronously through the beam provides an x-ray target. The machine now operates at about 1 Bev with about 5×10^8 electrons per pulse. It is expected eventually to operate at 1.5 Bev with intensity of 10^{10} electrons/pulse.

* Work supported by joint programme of the Office of Naval Research and the U. S. Atomic Energy Commission.

U3. Approximate Phase Plane Transformations for A. G. Synchrotrons. A. M. SESSLER, *Ohio State University and Midwestern Universities Research Association.**—The computational program necessary to study the stability of particle trajectories in A. G. Synchrotrons may be very much reduced, if one has available phase plane transformations. The transformations are used on high-speed computers, and so must be exactly area preserving, as well as of simple functional form, thus precluding the use of most simple perturbation theories. A method will be given, using the results of G. D. Birkhoff,[1] to construct an approximate transformation in the neighborhood of an equilibrium orbit, which satisfies these requirements. A perturbation solution in powers of the amplitude of oscillation is first obtained, and then transformed to normal form, in such a way that one can formally obtain an area preserving transformation of arbitrary accuracy. In terms of the newly introduced independent variables, the transformation is particularly simple, and one may by inspection obtain the betatron oscillation wavelength as a function of amplitude. The method does not correctly yield the stability limit of the oscillations. Application will be made to a one-dimensional A. G. Synchrotron with cubic nonlinearities.

* Supported by the National Science Foundation.
[1] See Volume II of Collected Mathematical Papers, Am. Math. Soc. (1950).

U4. Orbit Calculations for Fixed-Frequency Cyclotrons. D. S. FALK AND T. A. WELTON, *Oak Ridge National Laboratory.*—In order to obtain reliable design parameters for a high-energy (~one Bev) fixed-frequency cyclotron, we have constructed and run a flexible ORACLE code for computation of pertinent properties of the median plane magnetic field, equilibrium orbits, and small-amplitude focusing oscillations. Because of the need to economize on computation time and fast memory space, the novel procedure was adopted of assuming at each energy an equilibrium orbit, which departed from a reference circle by a sinusoidal function of angle. The radius of the circle is automatically adjusted to give the correct orbital frequency, and the amplitude of the sinusoid can be adjusted to alter the axial focusing. The magnetic field along the equilibrium orbit is calculated by differentiation and the linearized axial and radial focusing equations are then solved numerically through one sector of the accelerator to obtain the two focusing frequencies. Fields, orbit shapes, and frequencies are automatically printed out, allowing complete specification of the orbits of an accelerator in roughly half an hour. Agreement with approximate analytical results is excellent to within the accuracy of the formulae. This automatic procedure is particularly valuable where high-quality information for detailed design is required.

U5. Fixed-Frequency Electron Cyclotron with Azimuthally Varying Magnetic Fields. I. General Description. R. E. WORSHAM AND R. S. LIVINGSTON, *Oak Ridge National Laboratory.*—An electron cyclotron has been designed to extend to higher energies work done at Berkeley.[1] Experiments will be performed to evaluate the theory of high-energy fixed-frequency cyclotrons and to investigate certain conditions which cannot be readily calculated, e.g., beam behavior near an imperfection resonance. One or more resonances must be traversed to achieve energies in the Bev region. For a study of the $\frac{3}{2}$ resonance four azimuthal cycles (hills and valleys) are used; for simplicity, the field is not spiralled.[2] The greater accuracy required of the average field, ~0.05%, compared with that of the azimuthal variations in field, ~5%, makes separate control of the fields desirable. The average field, 40 gauss at the center and increasing to 56 gauss at the 12.2-in. radius (2/1 resonance), is produced by dished pole faces. The number of azimuthal cycles and amount of spiral can be changed simply by using different sets of poleface windings. The two-dee resonant system (112 Mc/sec) will accelerate electrons 1 kv/turn.

[1] R. Pyle, UCRL-2435 Rev. (1955).
[2] K. M. Terwilliger *et al.*, Phys. Rev. **98**, 1153(A), 1955.

U6. Fixed-Frequency Electron Cyclotron with Azimuthally Varying Magnetic Fields. II. Magnet Design. H. M. MOSELEY, *Texas Christian University,* AND R. E. WORSHAM, *Oak Ridge National Laboratory.*—The values of magnetic field obtained with the ORACLE (Falk and Welton, above) provide the basis for the design of the magnet for the electron cyclotron. Separated azimuthal and average field values were established by converting $F(\beta,\theta)$ to $F(r,\theta)$ and then expanding $F(r,\theta)$ in a Fourier series. The average field was used to determine magnetic equipotential surfaces, and hence the shape of the pole pieces. The azimuthal field variations are superposed on the average field through pole-face windings. Image theory was used to calculate the field of 8 identical pairs of windings. Each pair occupies a 45-deg sector and is symmetrically placed about and parallel to the median plane. Since currents in adjacent windings are equal and opposite there is minimum contribution to the average field. Provisions are made for varying the current in individual coils to provide for shimming and introduction of known field errors. Two sets of circular coils, concentric about the axis of the magnet and placed parallel to the sector windings, provide for varying the average magnetic field.

U7. Phase Stability in Fixed-Frequency Cyclotrons. T. A. WELTON, *Oak Ridge National Laboratory.*—A cogent objection to the idea of a high-energy fixed-frequency cyclotron lies in the extreme frequency precision required to accelerate at essentially constant phase with reasonable dee-voltage. Typically, a proton is required to make several thousand revolutions with a phase error of less than 90°. A simple procedure exists for easing this constraint. Imagine that the accelerating gaps spiral as the energy increases. Every gap traversal then results in a radial impulse which introduces a series of abrupt direction changes in the orbit. The value of this discontinuity varies as the phase of traversal varies. Also, the time required to reach the next gap varies with the value of the discontinuity. The elements of phase stability are then present, in that a late gap traversal can be arranged to lead to a decreased time until the succeeding traversal, and *vice versa*. Assume a machine to be available in which all equilibrium orbits have the same frequency. Excitation by spiral gaps, with frequency slightly off resonance, will result in accelerating orbits which automatically assume the correct

discontinuities of direction at the gaps to insure an average orbital frequency identical with the applied frequency.

U8. Median Plane Motion in the Spirally Ridged FFAG Accelerator.* F. T. COLE, *State University of Iowa*, L. J. LASLETT, *Iowa State College*, AND J. N. SNYDER, *University of Illinois and Midwestern Universities Research Association.*—We have investigated the motion in the median plane of the spirally ridged FFAG accelerator with a magnetic field

$$H_z = -H_0(r/r_0)^k[1 + f \sin(w^{-1} \ln(r/r_0) - N\theta)]$$

using the Electronic Digital Computer of the Graduate College of the University of Illinois (Illiac) to integrate numerically the exact equations of motion. Parameters were chosen in the ranges characteristic of the small FFAG accelerator under construction at Illinois, but the orbit phenomena appear to be independent of the machine size. The closed equilibrium orbit is very closely a biased sine wave, in good agreement with the analytical theory of Laslett.[1] The size of the region in the phase plane of stable oscillations about this closed orbit depends critically on the phase change per sector (σ) of the oscillation, which is a function of amplitude. The motion becomes unstable in most cases when σ approaches $\frac{2}{3}\pi$, though in some cases instability occurs at some other rational fraction of π. Interpretation of this instability will be discussed.

* Supported by the National Science Foundation.
[1] L. J. Laslett, Phys. Rev. **99**, 653(A) (1955).

U9. Ion Source for Multiply Charged Ions, KENNETH W. EHLERS, *University of California*, AND CARL E. ANDERSON, *Yale University.*—A pulsed, cold cathode ion source has been developed to produce multiply charged ions for use in a linear accelerator. Milliampere currents of such ions as He_4^{2+}, C_{12}^{2+}, N_{14}^{3+}, O_{16}^{3+}, Ne_{20}^{3+}, and smaller currents of S_{32}^{5+} and A_{40}^{6+} have been produced in focused beams. Mass spectra of the various ionization states produced by the arc will be presented. Constructional details of the source and its operating characteristics will be discussed.

U10. Polarized Internal Proton Beams in High-Energy Accelerators. RICHARD L. GARWIN, *IBM Watson Scientific Laboratory.*—Preliminary calculations show that it is feasible to produce completely polarized circulating proton beams in the Cosmotron or in the Bevatron, as well as in many lower energy machines. The beam intensity should not be much lower than that of the circulating beam now in use. The scheme proposed involves the production of atomic hydrogen, a large scale (apertures some centimeters in dimension) atomic beam separation of the electron spin states (producing a beam of 50% polarization) followed by a simple rf transition to depopulate the beam of the state with the wrong hyperfine splitting, yielding a beam almost 100% polarized. Estimates have been made of the beam intensity and of the depolarization suffered in the ion source. The possibility of recombination and of pumping the polarized, recombined hydrogen will be discussed and a proposed scheme detailed. The method is also suitable for deuterium.

U11. Control of Current Loading and Sparks in Ion Accelerating Tubes by Back-Biased Diaphragms.* J. L. MCKIBBEN, *Los Alamos Scientific Laboratory.*—Accelerating tubes commonly employed in electrostatic accelerators give a maximum voltage which is roughly proportional only to the square root of the length. An attempt has been made to achieve a more linear relationship of voltage with length by the use of diaphragms in the 20-ft long tube in the big Los Alamos accelerator. These diaphragms have a 1-in. central opening and are located at 2, 4, 8, 12, and 16 ft from the top. Current loading as indicated by an x-ray detector appears strongly at approximately 3½ megavolts with uniform potential distribution, but with proper field reversal or back bias on the normally positive side of the diaphragms this threshold is increased to 7½ megavolts. Tube sparks occur only slightly above the x-ray threshold at 7½ megavolts. The details of application of back bias are important and when properly adjusted the total voltage is very nearly the sum of the voltage on the sections between diaphragms. An interpretation of the mechanism underlying the operation of the diaphragms will be discussed on the basis of a charged-particle chain reaction found several years ago in a 2-ft length of this flat electrode tube. The phenomenon consists of particles releasing particles of opposite sign at the opposite end of the tube.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

FRIDAY MORNING AT 9:30

Panel Room

(P. R. BELL presiding)

Neutron Physics, II

UA1. Scattering of Neutrons by a Coulomb Field RICHARD WILSON* AND R. G. VOSS,† *Clarendon Laboratory, Oxford.*—A beam of polarized neutrons of an effective energy 100 Mev has been obtained by charge exchange scattering of protons at 26° from a beryllium target. These neutrons are carefully collimated. After scattering from a thick uranium scatterer at angles of ¼° to 1° they are detected by a large liquid scintillator. The asymmetry in the left to right scattering is measured. The angular distribution shows an increase of 30% from 1° to ¼°. The assymmetry increases as the angle decreases. These effects are in agreement with the predictions of Schwinger[1] for scattering of neutrons by interaction of the magnetic moment with a Coulomb field. The results enable the value and sign of polarization of the incident beam to be determined. The value 10±1.5% is in agreement with free *np* scattering at a comparable angle, and the sign agrees with other determinations.

* Now at Harvard University.
† Now at Liverpool University.
[1] J. Schwinger, Phys. Rev. **73**, 408 (1948).

UA2. Determination of Nuclear Radii for U^{238} and Th by Measurement of Potential Scattering Cross Section.* R. C. GARTH,† V. E. PILCHER, AND D. J. HUGHES, *Brookhaven National Laboratory.*—The nuclear radius, which has an important bearing on current nuclear theory, can be determined from the potential scattering section for slow neutrons. By measuring the total cross section between resonances and correcting for the effects of nearby levels a reasonably accurate value of the potential scattering cross section may be obtained.

The corrections to the observed cross section are computed from the experimental Breit-Wigner parameters of the levels. The cross sections of several thick samples of U^{238} and Th were measured at the Brookhaven fast chopper with particular care being taken to minimize instrument drifts and other sources of error. When analyzed by the method discussed above, these data give $\sigma_{pot}=11.2\pm0.8$ barns for uranium and $\sigma_{pot}=12\pm1$ barns for thorium. From these results, values of the nuclear radius, R, of $9.5\pm0.4\times10^{-13}$ cm and $9.8\pm0.5\times10^{-13}$ cm for U^{238} and Th are found. The R-values give γ_0's of 1.50 ± 0.06 cm and 1.60 ± 0.08 cm for the constant in the usual formula $R=\gamma_0 A^{\frac{1}{3}}\times10^{-13}$ cm. The nuclear radii obtained are much larger than those calculated by using a small value of γ_0 plus a constant. The above values of σ_{pot} are in good agreement with fast chopper results.

* Work done under contract with the U. S. Atomic Energy Commission.
† Now at Brooklyn College.

UA3. Total Cross Sections in the Kilovolt Region; Mg^{24}, Mg^{25}, Mg^{26}.† A. TAYLOR,* H. MARSHAK,‡ AND H. W. NEWSON, *Duke University.*—All three nuclides show resonant structure above 200 kev, but the samples were too thin to show much detail. There are resonances due to Mg^{25} at 20, 81, and 101 kev with approximate widths of 1, 9, and 10 kev, respectively. No resonance of comparable strength was found for Mg^{26} and only one for Mg^{24}. The latter, at 85 kev, was almost perfectly resolved with a peak cross section of 60 barns. This is very nearly the value to be expected from a $\frac{3}{2}^-$ state. The assignment is unambiguous since $l=0$ is ruled out by the high value of the peak cross section, and the width, $\Gamma=8$ kev, cannot be assigned to $l=2$ without exceeding the Wigner limit by a wide margin. The separated isotopes used were prepared at the Oak Ridge National Laboratory under the supervision of C. P. Keim.

† Supported in part by the U. S. Atomic Energy Commission.
* Now in the U. S. Navy, stationed at NAS, Pensacola, Florida.
‡ Now at Brookhaven National Laboratory, Upton, Long Island, New York.

UA4. Anisotropy in the Scattering of 55- to 105-kev Neutrons from Intermediate Weight Elements.* W. HAEBERLI AND R. C. BLOCK,† *Duke University.*—The ratio of the neutron differential scattering cross section at 175° to the cross section at 90° has been measured for ten elements between $A=64$ and $A=112$ for neutron energies of 55 to 105 kev. The angle of acceptance of the neutron detectors is 7°, the transmission of the scatterers, 60% to 90%. Due to the large neutron energy spread used (~10 kev) only weak resonance structure was observed. The measured 175° to 90° cross-section ratios have been corrected for multiple scattering and averaged over the energy interval $E^n=55$ to 105 kev. The ratios are: Zn, 1.0; Se, 1.08; Sr, 0.98; Zr, 1.25; Mo, 1.15; and Cd, 0.86 for those elements which consist predominantly of spin zero isotopes; and Cu, 1.0; As, 0.96; Nb, 0.98; and Ag, 0.92 for those elements with $I>0$. These ratios are in qualitative agreement with the complex square well potential model[1] which predicts a maximum 180° to 90° ratio at $A\sim94$ for spin-zero nuclei and ratios close to one for nuclei with large spin.

* Work supported by the U. S. Atomic Energy Commission.
† Now at Oak Ridge National Laboratory.
[1] Feshbach, Porter, and Weisskopf, Phys. Rev. **96**, 448 (1945).

UA5. Neutron Capture Gamma Rays from Individual Neutron Resonances.* R. G. BENNETT, A. E. WALTERS, C. A. FENSTERMACHER, AND L. ROSLER, *Yale University.*—Using the Yale linear electron accelerator as a pulsed source of photoneutrons, resonant energy neutrons have been selected on a time-of-flight basis, and the prompt γ rays resulting from single level capture have been examined with a 2½-in. NaI(Tl) crystal and an 80-channel pulse-height analyser. Individual γ rays have been resolved only below 1 Mev. Preliminary work suggested by a previous cross-section measurement[1] shows that a 260-kev γ ray, present in the spectra following capture in the 4.28- and 10.38-ev levels of Ta^{182}, is absent in the spectra from the 13.95-ev level. The γ ray should have been detected if it were approximately 20% as intense as in the former cases. The absolute intensity of a 600-kev γ ray following neutron capture in the 2.33-ev level of Te^{123} has been measured by comparison with the 478-kev γ ray from a thick B^{10} sample and is shown to be emitted in approximately 50% of the neutron captures.

* Work supported by the U. S. Atomic Energy Commission.
[1] T. F. Godlove and J. G. Carver, Phys. Rev. **99**, 1634 (A) (1955).

UA6. Pile Neutron Capture Cross Sections of Neptunium-239. H. W. LEFEVRE, E. M. KINDERMAN, AND H. H. VAN TUYL, *General Electric Company, Richland.*—An activation method was used to measure the neutron capture cross sections of neptunium-239. Two isomers of neptunium-240 have been reported: a seven-minute daughter of uranium-240[1] and a one-hour isomer produced by alpha bombardment of uranium-238.[2] Examination with a gamma scintillation spectrometer of the activity produced by neutron activation of neptunium-239 gave positive evidence for the seven-minute isomer as a product of neutron capture in neptunium-239. The one-hour isomer is also produced although the evidence for it was complicated by fission product activity. Genetic linkage between the isomers was not detected and is less than 5%. The measured cross sections for pile neutrons are 29 ± 6 barns and 17^{+17}_{-6} barns for the seven-minute and one-hour isomers.

These values are based upon a 2.8% abundance of the 1.5-Mev gamma of the seven-minute isomer and a 38-percent abundance for the 0.97 Mev gamma of the one-hour isomer. These results are relative to a gold thermal cross section of 95 barns.

[1] Knight, *et al.*, Phys. Rev. **91**, 889 (1953).
[2] R. M. Lessler, UCRL-2531 (unpublished).

UA7. Neutron Absorption by Fissionable Materials in the 5- to 50-kev Energy Range. R. L. MACKLIN, H. W. SCHMITT, AND J. H. GIBBONS, *Oak Ridge National Laboratory.*—The absorption cross section of U^{235} and Pu^{239} have been determined at six energies in the 5- to 50-kev energy region. Neutrons were obtained from the reaction $V^{51}(p,n)Cr^{51}$. The iodine in NaI(Tl) crystals was used as an activation detector. Transmissions of spherical shells of U^{235} and Pu^{239} metal of about one mean free path thickness were measured; the absorption cross sections were computed from these transmissions using methods similar to those of Bethe, Beyster, and Carter *et al.*[1-3] Corrections were included for fission neutron activation of the iodine, finite geometry (i.e., size, shape, and orientation of the crystal and finite source-to-detector distance), and other effects. The results show, in general, a decrease in absorption cross section with increasing energy up to about 30 kev and then a nearly constant value (up to 50 kev) of about 2.8 barns for U^{235} and 2.2 barns for Pu^{239}. Similar measurements for U^{233} at 4.4 and 11.8-kev neutron energy will be discussed.

[1] H. A. Bethe, Second Pittsburgh Conference on Medium Energy Nuclear Physics (1953).
[2] J. R. Beyster *et al.*, Phys. Rev. **98**, 1216 (1955).
[3] Bethe, Beyster, and Carter, Los Alamos Report LA-1429 (unpublished).

UA8. Neutron Electron Interaction.* E. MELKONIAN, B. M. RUSTAD, AND W. W. HAVENS, JR., *Columbia University and Brookhaven National Laboratory.*—A new determination of the strength of the neutron electron interaction has been made by measuring the variation of the transmission of a sample of liquid bismuth in the energy range 0.1 ev to 10 ev. The 200 planes of an NaCl crystal on the Columbia Crystal Spectrometer at Brookhaven National Laboratory were used for the energy selection. The liquid bismuth was contained in a two

compartment iron cell. The neutron beam passed through one compartment of the cell and the sample was pumped in and out for the transmission measurements. The temperature was regulated to 0.5°C. Vacuum jacket and radiation shields were used to minimize temperature gradients. Measurements were made at 300°C and 500°C. After corrections for the capture cross section of bismuth and the effect of liquid diffraction, a value of 4165±265 ev was obtained as the well depth of the square well potential with radius equal to the classical electron radius. The error assignment is the standard deviation arising from statistical fluctuations only. A repeat measurement with a new charge of bismuth is planned.

* This work was partially supported by the U. S. Atomic Energy Commission.

UA9. New Results with the High-Resolution Slow-Neutron Velocity Spectrometer Using the Nevis Synchrocyclotron.* G. GRIMM, J. S. DESJARDINS, J. ROSEN, L. J. RAINWATER, AND W. W. HAVENS, JR., *Columbia University.*—A new 128-channel time analyser has been completed for use with the high-resolution slow-neutron velocity selector system using the Nevis synchrocyclotron.[1] The new timing system allows self-indication resonance measurements at ~36 meters with a rectangular resolution function of 0.5, 1.0, or 2.0 microseconds full width. Detailed experimental results will be presented.

* This work was partially supported by the U. S. Atomic Energy Commission.
[1] Grimm, Rainwater, and Havens, Jr., Phys. Rev. **98**, 1161 (1955).

UA10. Atomic Distribution in Liquid Argon by Neutron Diffraction and the Cross Section of A^{36}. D. G. HENSHAW, *Chalk River Laboratories.*—The distribution of 1.04 A neutrons scattered by liquid argon at 84.1°K has been measured over the angular range 2.6 to 77 degrees. The small angle scattering previously reported[1] has been confirmed and shown to be incoherent in origin by measurements in the solid. From transmission measurements on enriched argon[2] a value of about 75 barns has been deduced for the total cross section of A^{36} for 1.10 A neutrons. Using this cross section for A^{36}, the small angle scattering has been explained in terms of isotope incoherence. Comparison of the scattering and transmission measurements has shown that the sign of the scattering length of A^{36} is probably the same as that of A^{40}. The angular distribution has been transformed to give the atomic distribution for liquid argon at 84.1°K. Maxima in the atomic distribution occur at 3.81 A and 7.0 A. The position of the first maximum is in the region of the minimum of the published two particle potential functions for argon, but, neglecting small oscillations which are probably spurious, the density rises steeply from zero at a radial distance of 3.1 A which is well inside the repulsive core of these potential functions.

[1] Henshaw, Hurst, and Pope, Phys. Rev. **92**, 1229 (1953).
[2] We are indebted to Professor W. W. Watson and Dr. J. W. Corbett of Yale University for the sample of A^{36} enriched gas on which the transmission measurements were made.

UA11. C^{13} Photoneutron Cross Section.* B. C. COOK AND V. L. TELEGDI, *The University of Chicago.*—The yield of neutrons from C^{13} for bremsstrahlung spectra up to 45 Mev has been measured with 1.1 g of C^{13} contained in elemental carbon enriched to 65% used as a target; neutrons were detected by 12 $B^{10}F_3$ counters embedded in paraffin. The energy independence of this counting was checked by comparing the yields for $C^{12}(\gamma,n)C^{11}$ from neutron and activity counting. The absence of gross distortions of the spectra at low energies was verified by comparing $D(\gamma,n)H$ yields with theoretical expectations. The $C^{13}(\gamma,xn)$ cross section, derived by Leiss and Penfold's method from the smoothed yield curve, exhibits two distinct peaks, at 14.0 and 23.5 Mev, respectively. Preliminary magnitudes of these peaks are: σ(14 Mev) = 3.5 mb, (~4 Mev half-width), σ(23.5 Mev) = 9.5 mb (~8 Mev half-width). The correspondence of the C^{13} giant resonance with that of C^{12} (measured here and elsewhere[1]) is strong evidence for "core" absorption in view of difference in (γ,n) thresholds in C^{13} and C^{12}. Whereas the lower peak can hardly be attributed to transitions of the $p_{\frac{1}{2}}$ neutron to the continuum, it is as yet not clear whether it should be interpreted as a superposition of transitions to C^{13*} levels or as a single $E2$ resonance of the type observed in $O^{16}(\gamma,p)$.

* Research supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Barber, George, and Reagan, Phys. Rev. **98**, 73 (1955).

FRIDAY MORNING AT 9:30

Terrace Room

(L. M. LEDERMAN presiding)

Heavy Mesons and Hyperons; Cosmic Rays

V1. Production of Unstable Particles by 2-Bev Pions.* H. BLUMENFELD, E. T. BOOTH, AND L. M. LEDERMAN, *Columbia University* AND W. CHINOWSKY, *Brookhaven National Laboratory.*—The magnet cloud-chamber investigation of the production of unstable particles in thin (two ¼-in. Pb and three ½-in. C) lead and carbon plates by 2-Bev pions is being continued. To date, 140 events have been recorded in which an incident pion collides in a plate, producing an interaction out of which comes one or more particles which subsequently decay in the chamber. The ratio of observed Λ^0 to θ^0 to $V^\pm$ decays is as 4:1.3:1. Eighteen associated production events are observed. These are: $\Lambda^0\theta^0$ (12), V^0V^- (1). Λ^0V^+ (3), θ^0V^+ (1), $\Lambda^0\Lambda^0$ (1). We will detail the following observations: (1) The backward c.m. emission of Λ^0's assuming $\Lambda^0-\theta^0$ production in the pion-nucleon collisions continues strong. (2) The ratio of Λ^0/θ^0 yield in carbon to that in lead is 2:4. (3) There is no observable correlation between the production and the decay planes of Λ^0's made in carbon. (4) The hypothesis of associated production is difficult to reconcile with the data unless particle mixtures or alternate decay modes are invoked for the θ^0. (5) Lifetimes of the Λ^0, θ^0 are being determined. (6) Charged $V^\pm$ yields are: Pb+ (8), Pb− (5), C+ (3), C− (5), with a mean decay path for both signs of ~5 cm in the chamber.

* Assisted by the U. S. Atomic Energy Commission and the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

V2. Production of Hyperfragments by 2.3-Bev Protons. R. HALL,* *Texas Technological College.*—A systematic study of 10 000 events produced in Ilford G.0 emulsions by the 2.3-Bev proton beam of the Brookhaven Cosmotron has been made in an effort to ascertain the threshold for the producion of hyper-

fragments. Since the existence of hyperfragments seems well established,[1] it is only necessary to observe that the Q of decaying fragments coming from stars is greater than 175 Mev (including the rest mass of any emitted pion). Only two such decays were observed, giving a ratio of hyperfragments to total stars of about 2×10^{-4}. The ratio reported by Fry, Schneps, and Swami[1] for 3-Bev protons was 10^{-3}. This fact, together with the predicted threshold of 1.57 Bev for the production of Λ^0 particles in nucleon-nucleon collisions,[2] seems to limit the possible values of the threshold energy.

* Now at Colorado School of Mines.
[1] Fry, Schneps, and Swami, Phys. Rev. **99**, 1561 (1955).
[2] R. G. Sachs, Phys. Rev. **99**, 1573 (1955).

V3. V-Particle Production by 1.9-Bev π^- Mesons.* G. G. Slaughter, E. M. Harth, and M. M. Block, *Duke University.*—A twenty-atmosphere hydrogen-filled diffusion cloud chamber in a magnetic field of 9500 gauss was exposed to a 1.9-Bev negative pion beam at the Brookhaven Cosmotron.[1] One case of neutral V-particle production and one case of charged V-particle production occurred in the gas, compared to the 195 elastic and inelastic π^--p scatters observed. The cross section for V-particle production in π^--p interactions is estimated to be of the order of 0.3 millibarn. In addition, 72 neutral V-particles and 22 charged V-particles, presumably produced in the stainless steel wall of the cloud chamber, were observed to decay in the gas; two of these neutral V-particles were observed to undergo β decay.[2] Classification, energy distribution, and angular distribution of the V-particles will be discussed.

* This work was supported by a joint Office of Naval Research and U. S. Atomic Energy Commission contract.
[1] The courtesy of R. P. Shutt and the cloud-chamber group at Brookhaven in generously providing equipment and these exposures is appreciated.
[2] Block, Harth, and Blevins, Phys. Rev. **100**, 959 (1955).

V4. Further Evidence on the Nature of the Neutral Particles in the Decay Scheme of the $K_{\mu3}$.* T. F. Hoang, M. F. Kaplon, and G. Yekutieli,† *University of Rochester.*—Recently it was shown in this laboratory[1] that the $K_{\mu3}$ decays via the scheme: $K_{\mu3}\rightarrow\mu+\pi^0+?$ The "?" represents a neutral particle with mass less than 217 Mev. The neutral particle could be either a π^0, γ ray, or a neutrino. We report here the analysis of a new case of $K_{\mu3}$ decay, and show that the neutral particle "?" is massless. The $K_{\mu3}$ was found in an area scanning of nuclear emulsions exposed to the K^+ beam of the cosmotron. The K^+ decays into a μ meson of 83 ± 8 Mev and an electron pair of 65 ± 17 Mev. We analyze the event in terms of the observed particles and the known interactions and arrive at the decay scheme: $K_{\mu3}\rightarrow\mu+\pi^0+?\rightarrow\mu+2e+\gamma+?$ The "?" here cannot be a π^0, since the maximum energy available for the μ meson if the decay is $K_{\mu3}\rightarrow\mu+\pi^0+\pi^0$ is only 75.7 Mev, and we observe a μ meson of 83 ± 8 Mev. We therefore conclude that the decay scheme of the $K_{\mu3}$ is $K_{\mu3}\rightarrow\mu+\nu+\pi^0$ (for a boson K-particle) and $K_{\mu3}\rightarrow\mu+\gamma+\pi^0$ (for a fermion K-particle).

* This research supported in part by the joint programs of the U. S. Atomic Energy Commission and the Office of Scientific Research, U. S. Air Force.
† On leave from the Weizman Institute of Science, Rehovoth, Israel.
[1] Yekutieli *et al.*, Phys. Rev. (to be published).

V5. Charged Hyperons in Emulsion.* J. Schneps, M. S. Swami, W. F. Fry, and G. A. Snow,† *University of Wisconsin.*—A total of 42 charged hyperon events have been studied in plates exposed to high-energy π^- mesons and protons as well as cosmic rays and stopped negative K-mesons. Nine decays in flight of hyperons produced by stopped K-mesons were observed, of which 5 decayed into charged π mesons and 4 into protons. The lifetime of the $\Sigma^\pm$ hyperon obtained from these 9 events is $3.4^{+1.4}_{-0.8}\times10^{-11}$ sec. Of the remaining 33 hyperons arrested in the emulsion, 14 caused stars and therefore are assumed to have been negative. Five decayed from rest into a charged π meson and 14 decayed into a proton. These 19 Σ hyperons are assumed to be positive. The mass of the Σ^+ hyperon can be obtained from an accurate measurement of the energy of the proton from the Σ decays at rest. The results of these measurements will be given.

* Supported in part by the U. S. Atomic Energy Commission and by the graduate school.
† Present address, Naval Research Laboratory, Washington, D. C.

V6. K^--Interactions.* D. Fournet, A. Pevsner, and D. M. Ritson, *M.I.T.*, and M. Widgoff, *Harvard University.*—A stack of 95 Ilford $G5$ emulsions, each 3 in.$\times$5 in.$\times600\mu$, was exposed in a focused K^--beam at the Berkeley bevatron. The average momentum of the K^--mesons entering the stack was 400 Mev. Along the track scanning of K^--tracks is being carried out, beginning at about 5 cm residual range for each meson. The total track length scanned thus far is about 5 meters, and the cross section in emulsion is found to be approximately geometrical. Although the characteristics of the stars in flight show absorption predominantly, a few examples of scattering have been observed. The difference of K^+- and K^--interactions confirms the Gell-Mann and Pais assignment of strangeness. The magnitude of the cross section relative to K^+'s can be understood in simple terms, and will be discussed at the meeting.

* This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

V7. Simple Photometric Device for the Analysis of Nuclear Emulsions.* F. Mathews, T. Pohrte, and R. Hall, *Colorado School of Mines.*—A new approach to the problem of photometric measurement of ionization in nuclear emulsion will be described. Although other devices have been used previously for photometric measurements,[1-3] the simplicity and stability of this instrument should make it a more widely accepted research tool. Preliminary measurements indicate that the opacity R, as defined by Ceccarelli and Zorn,[3] is independent of the depth of the track in the emulsion, thus eliminating one of the most serious objections to the use of photometric methods. Data indicating the sensitivity and range of applicability of this instrument will be presented.

* Work supported by the Colorado School of Mines Foundation, Inc.
[1] Blau, Rudin, and Lindenbaum, Rev. Sci. Instr. **21**, 978 (1950).
[2] von Freisen and Kristianson, Nature **166**, 686 (1950).
[3] Ceccarelli and Zorn, Phil. Mag. **43**, 356 (1952).

V8. Anomalous Heavy Primary Cascade. Herman Yagoda, *National Institutes of Health.*—A stack of Ilford $G5$ emulsions ($9\times9\times1$ cm) was flown to a peak altitude of 136 miles from White Sands, New Mexico, in the tip of Viking Rocket No. 10, with only 2 g cm^{-2} of superimposed metallic absorber. A heavy primary of $Z=14\pm1$ enters the detector and produces a series of 5 collisions over a total path length of 2.49 cm of emulsion. The collision mean free path 2.66 g cm^{-2} for this event is about 20 times smaller than normal. The probability of the chain occurring by chance as a result of a series of abnormal fluctuations in the geometric mean free path is estimated to be 1.5×10^{-6}. The path length between collisions and the disintegration products follow:

A	>0.031 cm	0+1 Si
B	0.361	1(B−Li−He)+4 Si
C	0.103	3+18 B
D	0.795	0+3 Li
E	2.200	7+6 He

The energy per nucleon of the incident primary is about 18 Bev (basis, the angles between the heavy fragments emerging from collision B). Potential mechanisms for augmenting the collision cross section will be discussed.

V9. Absolute Intensity of Low-Energy Cosmic-Ray μ Mesons.* A. FAFARMAN,† *New York University.*—A 1-kg cylindrcal plastic scintillator has been used as both the detector and absorber for the stopping of (omnidirectional) low-energy cosmic-ray μ mesons. Simultaneous delayed coincidences in each of two photomultipliers which view the scintillator serve to identify the decays of stopped mesons. Correction is made for mesons which decay outside the recorded delay interval. A further correction is made for edge effects (decay beta particles which escape from the scintillator with insufficient energy loss to actuate detector). The number of stopping mesons of average range 7 g/cm² (air equivalent) is 6.93×10^{-6} sec^{-1} g^{-1}. Assuming a $\cos^3\theta$ distribution in zenith angle yields for the vertical intensity 4.41×10^{-6} g^{-1} sec^{-1} sterad^{-1}. The corrections imply these values to be lower limits.

* Assisted by the U. S. Office of Naval Research.
† Now at Hughes Research and Development Laboratories, Culver City, California.

FRIDAY MORNING AT 9:30

Boston Room

(K. G. McKAY presiding)

Invited Papers in Solid-State Physics

VA1. Thermoelectricity and Thermal Conduction in Semiconductors. T. H. GEBALLE, *Bell Telephone Laboratories.* (30 min.)

VA2. Ferromagnetic Domain Walls. C. P. BEAN, *General Electric Company.* (30 min.)

VA3. The Theory of the Polaron. DAVID PINES, *Princeton University.* (30 min.)

VA4. Long Living Excited States in Solids. H. P. KALLMANN, *New York University.* (30 min.)

FRIDAY MORNING AT 9:30

Empire Room

(C. N. YANG presiding)

Theoretical Physics, VI

W1. Transition Amplitudes as Sums over Histories. W. TOBOCMAN, *Institute for Advanced Study.*—An explicit sum over histories expression for the transition amplitude is constructed on the basis of the canonical formalism of quantum mechanics. This expression can be shown to coincide with the Feynman principle when the Hamiltonian is classical in form and dynamical independence is expressed in terms of the commutation of operators. In general, the sum over histories differs somewhat from Feynman's sum but still involves the exponential of the action, $S=\int(p\dot{x}-H)dt$. However, for the Dirac field, where dynamical independence implies the anticommutivity of operators, the sum over histories has a form completely different from the Feynman principle.

W2. Fluctuations, Irreversible Processes, and Feynman Integrals over Paths. D. L. FALKOFF, *Brandeis University and Lincoln Laboratory.**—The statistical theory of irreversible processes as given by Onsager and Machlup[1] yields an expression for the conditional probability that a fluctuating thermodynamic variable, α, takes on specified value α_2 at time t_2 given its value α, at time t_1 in terms of the minimum of the time integral of appropriate dissipation functions ϕ and ψ, quadratic in $\dot{\alpha}$ and α respectively. This formalism may be extended to give not only transition probabilities, but also to assign probabilities to fluctuation paths. Namely, each path $\alpha(t)$ is assigned a probability proportional to $e^{-(1/2k)\int_{t_1}^{t_2}}\times[\phi+\psi]dt$ with ϕ and ψ the above functions of the path. The foregoing conditional probability then may be obtained by performing the integral over all paths as in Feynman's form of quantum mechanics.[2] With this extension of the formalism, one can then also perform averages over fluctuation paths.[3]

* The research reported in this document was supported jointly by the Department of the Army, the Department of the Navy, and the Department of the Air Force under Air Force Contract.
[1] Onsager and Machlup, Phys. Rev. **91**, 1505 (1953).
[2] R. P. Feynman, Revs. Modern Phys. **20**, 367 (1948).
[3] Montroll, Commun. Pure and Appl. Math. (November, 1952).

W3. Scattering in Field Theory.* H. EKSTEIN, *Armour Research Foundation.*—In presence of composite particles, the usual statement of the scattering problem is inadequate, because it is impossible to split off an "interaction" part of the Hamiltonian which vanishes in effect when the particles are distant. The following statement of the problem is proposed: the four Heisenberg operators P_μ of the total energy-momentum vector can asymptotically ($|t|=\infty$) be written as integrals of mutually commuting operators $A_r^{(\pm)\dagger}(\mathbf{k})k_{r\mu}A_r^{(\pm)}(\mathbf{k})$ which represent the four-momenta of outgoing and incident particles, respectively. Asymptotic observables (cross sections) are expressed in terms of simultaneous eignefunctions $\psi^{(\pm)}$ of these operators. The problem is the determination of these physical operators or their simultaneous eigenfunctions in terms of the usual field operators. In the simplest cases, the $A^{(\pm)}$ are essentially the well-known $\psi_{\text{out}}^{\text{in}}$ of Yang and Feldman, i.e., the asymptotic forms of the field operators. In general, no such identification is possible, but an integral equation for the functions $\psi\pm$ can be given. The inhomogeneous term of the integral equation is expressed in terms of one-particle eigenfunctions of the Hamiltonian.

* Work performed at Argonne National Laboratory.

W4. Insensitivity of the Scattering Matrix. KATSUMI TANAKA, *Argonne National Laboratory*, AND H. EKSTEIN, *Armour Research Foundation.**—From the preceding abstract, the following general S-matrix is defined:

$$S_{nm} = \lim_{\substack{t=\infty \\ \tau=-\infty}} (\exp[i(H-E_n)t]\Phi_n, \exp[i(H-E_m)\tau]\Phi_m),$$

where the basis functions Φ_n are defined as "products" of one-particle (elementary or composite) eigenfunctions of the Hamiltonian H. It is conjectured that this S-matrix is insensitive toward a substitution for the rigorous one-particle states of any approximate state which, by adiabatic switching-on of the interaction, is carried into a rigorous one-particle state. This conjecture, first suggested by the fact that the usual form of the S-matrix contains bare particle states, is supported by the proof that the S-matrix element between one bare and one "real" particle (e.g., bare meson and real nucleon, bare nucleon and real meson, one bare and one real nucleon) is exactly correct. The equivalence with Low's form of the S-matrix element for nucleon-meson scattering is one case.

* Work performed at Argonne National Laboratory.

W5. Scattering Matrix Elements for Complex Potentials.* FRANKLIN POLLOCK AND BERNARD MARGOLIS, *Columbia University.*—The problem of treating the scattering of particles by two potentials V_1 and V_2, where the Schroedinger equation involving V_1 alone is soluble, is extended to apply to the case in which V_1 is complex. No restriction as to reality is placed on V_2. The matrix elements occuring in scattering problems now involve solutions of the adjoint equation as well as the Schroedinger equation itself. The results will be applied to problems related to the nuclear scattering of particles in regions where the compound nucleus model can be considered valid.

* This work was partially supported by the U. S. Atomic Energy Commission.

W6. Scattering by the Approximate Thomas-Fermi Potential. J. MAYO GREENBERG,* *Rensselaer Polytechnic Institute.*—Complex scattering amplitudes for scattering of electrons from approximate Thomas-Fermi potentials over the range of atomic numbers have been computed by the method of Moliere[1] and compare with results at 40 kev using the partial waves treatment.[2] In spite of numerous approximations made in the calculation, surprisingly good agreement over a certain range of θ and Z is found for the values of arg $f(\theta)$ obtained by the two methods. However, as was to be expected, the absolute values of $f(\theta)$ are in complete disagreement until sufficiently large values of the scattering angle are reached. The Schwinger variational method has also been applied to this problem and the calculations include the effect of varying the wave number in the plane wave trial functions.

* Work supported by the National Science Foundation.
[1] G. Moliere, Z. Naturforsch. **2a**, 133 (1947).
[2] J. A. Ibers and J. A. Hoerni, Acta Cryst. **7**, 405 (1954).

W7. Short Wavelength Scattering Approximations.* L. I. SCHIFF, *Stanford University.*—The Born series for the exact scattering amplitude associated with the Schrodinger equation is simplified by applying the stationary phase approximation in the short wavelength case. The series can then be summed in two ways. One of these leads to an expression already obtained by Glauber,[1] who used the WKB approximation for the wave function in the integral equation for the scattered amplitude. The other yields a superficially different expression first derived by the author with the help of a WKB approximation for the Green's function. The two expressions are equivalent, but Glauber's seems to be slightly more convenient for numerical computation. This point, and the extension to the Dirac equation, will be discussed.

* Supported in part by the Air Force Office of Scientific Research.
[1] R. Glauber (private communication).

W8. Extension of the Bohr-Peierls-Placzek Relation to Nonzero Scattering Angles.* DAVID Y. WONG AND JOHN S. TOLL, *University of Maryland.*—From probability conservation, Bohr-Peierls-Placzek[1] derived the relation between total cross section σ and the imaginary part of the forward scattering amplitude: $\sigma(k) = (4\pi/k) Im A(k,0)$. The interference between primary and forward scattered waves compensates the total scattering. A similar relation for nonzero scattering angles is derived by considering two incident plane waves intersecting at the scatterer. The interference of the complex incident wave and the scattered wave is significant along the two directions of incidence. For the case of a spherically symmetric scattering center, the result is,

$$\frac{4\pi}{k} \mathrm{Im}A(2\alpha) = \mathrm{Re}\int_0^{2\pi}\int_0^{\pi} \times A^*[\cos^{-1}(\cos\theta\cos\alpha - \sin\theta\sin\alpha\cos\phi)] \times A[\cos^{-1}(\cos\theta\cos\alpha + \sin\theta\sin\alpha\cos\phi)]\sin\theta d\theta d\phi.$$

This relation can be used to obtain higher-order terms in $\mathrm{Im}A(k,\theta)$ from lower orders of $A(k,\theta)$. The above relation can be derived also from the unitarity of the S-matrix.

* Assisted by the National Science Foundation.
[1] Bohr, Peierls, and Placzek, Nature **144**, 200 (1939).

W9. (Abstract withdrawn.)

W10. Tensor Potentials and Wave Functions Constructed Explicitly from S Matrices.* T. FULTON,† *Institute for Advanced Study*, AND R. G. NEWTON, *Indiana University.*—From an S-matrix that is a rational function of the wave number k and that couples angular momenta l and $l+2$, the underlying noncentral potential which produces bound states of given binding energy and mixture, and the wave function are explicitly obtained. The method is one of solving the recently generalized GelIfand Levifan integral equation[1] by an extension of a technique due to Bargmann (unpublished). The resulting potentials are the first ones known for which the two coupled radial Schrödinger equations for angular momenta l and $l+2$ are solvable in closed form. Applications to cases of

physical interest, such as the neutron-proton interaction, will be discussed.

* Most of this work was done at the Institute for Advanced Study while both authors held F. B. Jewett Fellowships.
† National Science Foundation Postdoctoral Fellow.
[1] R. G. Newton and R. Jost, Nuovo cimento **1**, 590 (1955); R. G. Newton Phys. Rev. **100**, 412 (1955).

W11. On the Transition From Bound State to Scattering Theory.* A. REIFMAN† AND S. DEWITT,‡ *University of California, Berkeley,* AND R. G. NEWTON, *Indiana University.*—An operator that transforms an "unperturbed" two-particle eigenvector belonging to the discrete spectrum of an individual potential well for each particle into that which includes a short-range interaction between them is examined in the limit as the well width tends to infinity. It is found to approach the K-operator, which satisfies the integral equation that uses the principal value of the kernel. The result sheds light on Brueckner's equations,[1] which can now be formulated entirely in bound-state language. The connection between forward scattering amplitude and energy shift used in a recent paper[2] on the π-mesic atom is also commented on.

* This work was performed at the University of California, Berkeley, under the auspices of the U. S. Atomic Energy Commission.
† Present address: Lockheed Aircraft Corporation.
‡ Present address: University of California Radiation Laboratory, Livermore.
[1] K. A. Brueckner, Phys. Rev. **97**, 1393 (1955), and previous papers referred to there.
[2] Deser, Goldberger, Baumann, and Thirring, Phys. Rev. **96**, 774 (1954).

W12. Eigenfunctions and Eigenvalues in Symmetric Systems.* M. A. MELVIN, *Florida State University.*—The method of finding symmetry-adapted functions, or SAF's, belonging to the various "symmetry types"[1] of a group $\mathfrak{R}$ is simplified. This implies a concurrent simplification in the process of expressing the eigenfunctions or eigenvalues of a complicated system in terms of combinations of given functions (or matrix elements) obtained in a simplified problem. This process occurs in the vibrational problem of determining molecular symmetry-coordinates and frequencies, and in the quantum problem of determining approximate molecular, atomic, or nuclear eigenstates. A standard method for finding an SAF belonging to a given symmetry type of a group $\mathfrak{R}$ is to project any given function with respect to the type; the projection operator is a weighted sum of the operations of $\mathfrak{R}$. It is shown here that each projection operator can be written simply as an order-independent product of factors. In many cases, the product is one of mere two-term factors, whereupon the projection process becomes especially simple. The structures of all the point symmetry groups are analyzed, and tables of factored projection operators for all symmetry types are given. An example of a three d-electron ion, in a field of cubic symmetry, is treated to illustrate the method of factored projection operators.

* Assisted by the U. S. Atomic Energy Commission and by the Research Council of Florida State University.
[1] Abbreviation for "rows of the irreducible representations."

FRIDAY MORNING AT 9:30

Manhattan Center, Gold Room

(A. B. BESTUL presiding)

Division of High-Polymer Physics and Society of Rheology
Symposium on the Rheology of Polymers

WA1. Viscoelastic Properties of Crystalline and Amorphous Polymers. A. V. TOBOLSKY, *Princeton University.* (30 min.)

WA2. The Normal Coordinate Treatment of Relaxation Processes in Polymers. B. H. ZIMM, *General Electric Company.* (40 min.)

WA3. Mechanical Relaxation Spectra and Friction Coefficients and Their Dependence on Polymer Structure. J. D. FERRY, *University of Wisconsin.* (30 min.)

WA4. Stress Relaxation in Concentrated Solutions of Polymethylacrylate: Molecular-Weight Dependence. J. M. WATKINS, *E. I. du Pont de Nemours & Company.* (30 min.)

FRIDAY AFTERNOON AT 1:45

Grand Ballroom

(R. T. BIRGE presiding)

Business Meeting of the American Physical Society

FRIDAY AFTERNOON AT 2:45

Manhattan Center, Gold Room

(A. B. BESTUL presiding)

Symposium on the Rheology of Polymers *(concluded)*

X1. The Numerical Inversion of Relaxation Data to Distribution Functions of Relaxation Times. P. J. BLATZ, *Aerojet-General Corporation.* (30 min.)

X2. Some Remarks on the Normal Stress Effect. R. S. RIVLIN, *Brown University.* (30 min.)

X3. The Non-Newtonian Rheology of Raw Rubber. M. MOONEY, *United States Rubber Company.* (30 min.)

X4. Stress Analysis in Viscoelastic Materials. E. H. LEE, *Brown University.* (30 min.)

FRIDAY AFTERNOON AT 2:45

Terrace Room

(M. DEUTSCH presiding)

Apparatus of Nuclear Physics; Positronium

XA1. Mercury Vapor Jet as a High-Vacuum Target.* W. RALL, R. BERINGER, M. S. MALKIN, AND C. E. ANDERSON, *Yale University.*—Experiments have been conducted to develop a continuous supersonic mercury vapor jet providing a surface density in the range 1 $\mu g/cm^2$. Such a jet is to be used to strip additional electrons from heavy ions after they have been accelerated to a velocity of about 1.4×10^9 cm/sec to enable more efficient acceleration in a second stage of a linear heavy ion accelerator. Jet throughputs ranging from $\frac{1}{2}$ to 1/20 g/sec have been achieved yielding surface densities in the range 5 to 0.5 $\mu g/cm^2$. Vacuums as good as a few times $10^{-6}mt$ can be maintained in the 1 in. diameter beam bore tube transverse to the plane of the jet. When the bore tube section near the jet is cooled to $-80°C$ rather than liquid nitrogen temperature, this vacuum becomes a factor of 10 to 15 worse. Similar work[1] has been brought to our attention, after the inception of this study, using CO_2 in a similar manner to obtain doubly ionized helium ions.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] Geller and Prevot, Compt. rend. **238**, 1578 (1954).

XA2. High-Sensitivity Ultraviolet Spectrometer.* W. BENNETT AND C. S. WU, *Columbia University,* AND V. HUGHES, *Columbia University and Yale University.*—A high-sensitivity ultraviolet spectrometer has been developed employing a quartz prism spectrometer and a photomultiplier scanning system. The range between 2300 and 4300 A is divided into 270 channels and 10 channels containing 2 scalers each are scanned at a time. The photomultiplier tube is cooled to liquid nitrogen temperature to minimize thermal noise and a 30 *c/s* shutter is placed in front of the spectrometer slit. A square wave in phase with the shutter is used to switch between the 2 scalers in each channel. The difference between the 2 scalers represents the total number of photoelectrons recorded in that channel during a run. The detection limit of the system is about 20 photoelectrons/minute. The apparatus has been used to measure the line spectra produced by α particles stopping in various gases, and the states involved in the transitions have been tentatively identified. The implication to gas scintillation counters will be discussed.

* This work was partially supported by the U. S. Atomic Energy Commission.

XA3. Some Experimental Aspects of Coupling Slow and Fast Reactor Systems.* W. A. REARDON AND F. H. MARTENS, *Argonne National Laboratory.*—During the course of some studies of spectral equilibrium in the Fast Exponential Program (ANL-5379), it became necessary to investigate the effect of the fast assembly on the thermal source reactor. The techniques and experimental results will be described, in particular the effect of an air gap between the slow and fast assemblies will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

XA4. Pneumatic Local-Type Pile Oscillator.* BORISAS CIMBLERIS, SNSE, *Argonne National Laboratory.*—An intermittent pile oscillator of the local neutron flux depressor type was built for use in the CP-5 reactor. An air cylinder is mounted in a shielding plug located in a vertical hole within the graphite reflector. The piston rod drives an aluminum tube with a 3-ft stroke. Loading of the tube with a sample is done through the plug. Timing of the solenoid valve is achieved by a cam-actuated device, with a 20-sec period (1-sec travel time). The detector is a hollow cylindrical boron-10 coated ion chamber. The detecting circuit uses a vibrating reed electrometer, a bucking current source and a strip-chart recorder. Operation with the reactor shut down (photoneutron flux) proved to be the most satisfactory. Samples of several elements were oscillated and the results are being analyzed.

* Work supported by a fellowship of Conselho Nacional de Pesquisas (Brazil).

XA5. Annihilation Lifetimes of Positrons in Liquid Helium, Superconducting Lead, and Superconducting Vanadium. R. L. GRAHAM, D. A. L. PAUL, AND D. G. HENSHAW, *Chalk River Laboratories.*—Measurements have been made using thin positron sources of Na^{22}, a helium cryostat with a narrow tail, and IP21-stilbene scintillation counters connected to a 2×10^{-9} sec coincidence circuit. Analysis of the resolution curves obtained when the positrons annihilate in samples of pure lead, commercial lead, and vanadium shows that there is no difference between the lifetimes in the normal and superconducting states in excess of the experimental error of 5×10^{-11} sec. Results for annihilation in liquid He show the presence of a strong component with $\tau=2.7\pm0.3\times10^{-9}$ sec at 4.2°K. Current investigation suggests that this lifetime decreases as the He temperature is lowered, and that the abundance of this component is greater than that found for most amorphous materials.[1] The result on superconducting lead agrees with Schafroth and Marcus,[2] and those on He suggest that the reported change in lifetime in superconductors[3,4] might have been due to the annihilation of some positrons in liquid He.

[1] R. E. Bell and R. L. Graham, Phys. Rev. **90**, 664 (1953).
[2] S. M. Schafroth and J. A. Marcus, Bull. Am. Phys. Soc. **30**, 64 (1955).
[3] R. Stump and H. E. Talley, Phys. Rev. **96**, 904 (1954).
[4] W. E. Millett, Phys. Rev. **94**, 809 (1954).

XA6. Recent Experiments on Positron Lifetimes in Solids and Liquids.* H. S. LANDES, S. BERKO, AND A. J. ZUCHELLI.—Bell and Graham's[1] measurements of the temperature variation of the "anomalous" positron lifetime (λ_2) in amorphous solids, have been extended down to liquid helium temperatures. The complete τ_2 *vs* T curve shows a marked deviation from linearity; for Teflon we obtain $\tau_2=2.0\pm0.2\times10^{-9}$ sec at liquid helium temperature. Previous to these measurements a linear dependence has been assumed, based mainly on the 3-photon rate *vs* temperature measurements of Graham and Stewart[2] and Wagner and Hereford.[3] The measurement of lifetime of positrons annihilating directly in liquid nitrogen indicates no τ_2 component. Following a suggestion of Garwin, *n*-type, *p*-type, and pure germanium have been studied. No τ_2 component appears in either sample. The experiment studying quenching of the τ_2 lifetime in benzene by an organic free radical has been completed. The data can be best fitted with a model assuming fast, but velocity dependent, capture rates, about 69% of all positrons annihilating from the free state. The triplet-singlet conversion rate introduced by the

addition of the free radical yields a conversion cross section $\sigma = 4.7 \times 10^{-17}$ cm².

* Supported by the Office of Naval Research and the Office of Ordnance Research.

[1] R. E. Bell and R. L. Graham, Phys. Rev. **90**, 644 (1953).
[2] R. L. Graham and A. T. Stewart, Can. J. Phys. **32**, 678 (1954).
[3] R. T. Wagner and F. L. Hereford, Phys. Rev. **99**, 593L (1955).

XA7. Angular Correlation of Annihilation Radiation in Various Solids. G. LANG AND S. DEBENEDETTI, *Carnegie Institute of Technology.**—The angular correlation of gamma rays from two quantum positron annihilation has been observed in both *n*- and *p*-type germanium. Both agree remarkably well with the correlation which one would expect for a Fermi electron gas containing four electrons per atom. No difference between the two types was found. Cooling of the *n*-type to insure a full valence band also produced no difference. Measurements of annihilation radiation in alkali halides show distributions which do not resemble a free electron distribution and which appear to depend only on the halogen atom. The widths of the curves increase with the ionization potentials of the halogens, as would be expected if one were to assume that the positrons annihilate predominatly with the outer electrons of the negative ions.

* Research supported by the National Science Foundation.

XA8. Formation of Positronium in Gases.* E. P. DULIT, B. GITTELMAN, AND M. DEUTSCH, *M.I.T.*—The relative rate of two-photon and three-photon annihilation of positrons in gases has been studied under various conditions, using coincidence and scintillation spectrometer techniques. In commercial (welding grade) argon about 33% of the positrons form positronium; in freon about 40%. Addition of small amounts of a polyatomic gas to argon enhances formation for concentrations up to about 0.01%. For higher concentrations the formation decreases again, approaching the value for the pure polyatomic gas. This behavior is interpreted by a model considering the cross sections for formation of positronium, for inelastic collisions, for annihilation of free positrons and, in some cases, for quenching of *ortho*-positronium. Rough values of these cross sections deduced from the results are in general agreement with corresponding cross sections for ionization and excitation by electrons. Some results concerning the effects of electric and magnetic fields will also be presented.

* Supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.

XA9. Quenching of Orthopositronium in Gases.* B. GITTELMAN, E. P. DULIT, AND M. DEUTSCH, *M.I.T.*—We have studied the effect of gas pressure, temperature and magnetic fields on the quenching of three-photon annihilation in argon by the addition of NO, Cl_2, or O_2. Quenching by NO and Cl_2 is approximately proportional to the amounts introduced, indicating a mechanism effective for positronium atoms at all energies. About half of the *ortho*-positronium is quenched by oxygen at low partial pressure (one mm Hg). Additional oxygen is much less effective, indicating two different mechanisms operating at thermal and higher energies, respectively. Magnetic fields enhance the effect of NO and O_2, suggesting reorientation of the *ortho*-positronium spin in collisions. Probably most of the quenching in these gases is due to collision-induced triplet-to-singlet transitions. Absence of magnetic field effects in chlorine suggests capture of *ortho*-positronium to form a metastable "compound." This is consistent with the dependence of the quenching rate on total gas pressure which indicates breakup of the compound by collisions at a rate comparable with the annihilation of the positron in the molecule.

* Supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.

Invited Paper

XA10. The External Proton Beam of the Brookhaven Cosmotron. S. L. RIDGWAY, *Brookhaven National Laboratory.* (20 min.)

FRIDAY AFTERNOON AT 2:45

Panel Room

(RICHARD WILSON presiding)

Neutron Physics, III

Y1. Proposed Pulsed Neutron Source Using Cyclotron Phase Bunching.* JAMES E. DRAPER, *Brookhaven National Laboratory.*—For resonance neutron spectroscopy using a fixed frequency cyclotron, short neutron bursts are usually obtained by pulsing the arc. For example, the BNL 60-in. cyclotron now produces deflected beam pulses 1 milliampere by 0.5–2 μsec (adjustable) with a repetition period of 200–10 000 μsec. Measurements of this external beam show that a 1 μsec pulse consists of 11 (11 megacycle rf) bursts of duration ~5 millimicroseconds. Calculations, employing the BNL cyclotron parameters, predict that while this pulse is circulating near deflection radius, the 11 orbits have a total azimuthal span of ~50 degrees and a radial span of less than 1.7 in. If pulsed vertical deflection[1] were applied to this circulating group of bursts and were properly phased with the rf, the calculated interval over which the group is collected on a target above the median plane is ~12 millimicroseconds. The associated neutron energy resolution would be 10 ev at 2 kev for a 5-meter flight path. The predicted integrated yield is $\sim 10^{12}$ neutrons per second.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] Grimm, Rainwater, and Havens, Phys. Rev. **98**, 116(A) (1955).

Y2. Production of Short Bursts of Neutrons.* M. P. NAKADA, V. J. ASHBY, MARK HARRIS, AND WALTER KLEIN, *University of California, Livermore.*—Less than 4 millimicrosecond bursts of ions have been produced by sweeping the dc beam of the Cockcroft-Walton past a slit and by "klystron" bunching those ions which pass through the slits. The ions then produce neutrons in a tritium loaded target. The intensity is a factor of five better than sweeping alone.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

Y3. Neutron Filters for the 4 to 8.75 A Wavelength Range on the Single Crystal Neutron Spectrometer.* F. T. GOULD, T. I. TAYLOR, AND W. W. HAVENS, JR., *Columbia University and Brookhaven National Laboratory.*—When a mica crystal is used as monochromator for a neutron crystal spectrometer with a thermal reactor beam more than 99% of the coherently diffracted intensity is of order higher than the first for wavelengths greater than (4 A). The removal of these higher orders by using filters of Be, BeO, Bi, Mg, and several forms of graphite at liquid nitrogen temperature was investigated. The filters used to cover this interval were 8 in. of Be from

4–6 A, 4 in. of Be, and 10 in. of BeO from 6–8.25 A, 4 in. of Be, 10 in. of BeO, and 2 in. of specially crystallized Bi from 8.25–8.75 A. Measurements designed to detect higher order show it to be less than 1% of filtered beam intensity over the entire region. Counting rates of 1000/sec at 4 A and 32/sec at 8.75 A were obtained. Mg and graphite were found not to be suitable for filtering. Curving a laminated crystal to form the beam also increases the intensity substantially. The results of cross-section measurements of Au and Zr, Ti, Pd, and their hydrides using this arrangement will be presented.

* This work was partially supported by the U. S. Atomic Energy Commission.

Y4. Subthermal Neutrons from a Crystal Spectrometer with a Mechanical Monochromator.* N. HOLT, B. M. RUSTAD, AND F. GOULD, *Columbia University and Brookhaven National Laboratory.*—The useful range of the Columbia neutron crystal spectrometer has been extended to 11.5 A with the installation of a high transmission mechanical monochromator. A focused mica crystal is used for the primary monochromator. Since neutrons from the Brookhaven Reactor have a Maxwellian distribution, a subthermal beam reflected from the crystal contains many orders, the higher orders being about 1000 times more intense than the first order. These higher orders are removed by a mechanical monochromator consisting of a rotor with 80 helical slots set at a pitch of 800 cm. The slots are defined by 0.040-inch stainless steel blades plated with cadmium. The transmission of the rotor is 80% for first-order neutrons, and the short wavelength cutoff of the resolution function is 0.73 λ_0. Typical intensities for a $\frac{1}{4}\times 2$ inch beam are 1850 count/sec at 8.5 A and 500 count/sec at 11.5 A with background rates of 1 and 3%, respectively. The gold cross section measured between 8.5 and 11.5 A follows the $1/v$ law with a slope of 54.5 ± 0.2 b/A in agreement with measurements at shorter wavelengths.[1]

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] References listed by D. J. Hughes and J. A. Harvey in *Neutron Cross Sections* (U. S. Government Printing Office, Washington 1955).

Y5. Reflectivities of Various Crystals for Thermal Neutrons.* M. W. HOLM, *Phillips Petroleum Company.*—As a part of the MTR Crystal Spectrometer program a study is being conducted to assess the merits of the numerous natural and synthetic crystals available for use as neutron monochromators. The ideal repertory would consist of a series of crystals having appropriate interplanar spacings, low thermal absorption cross sections, high reflectances, good suppression of higher orders, and small mosaic spreads. With this in mind, structure factors and Debye-Waller temperature-correction factors have been computed for a number of crystals in the cubic, tetragonal, orthohombic, hexagonal, and trigonal systems. In addition, reflectivity has been computed as a function of glancing angle for a number of potentially useful planes of such crystals as rock salt, calcite, lead, and beryllium. Certain generalizations appear which permit the selection of suitable planes to be made with a minimum amount of calculation.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

Y6. Corona Counter for Thermal Neutrons. C. W. PETERS AND F. E. JABLONSKI, *U. S. Naval Research Laboratory.*—The corona counter is normally sensitive to alphas. If the electrodes are coated with enriched boron, the counter is sensitive to thermal neutrons. The counters tested consist of four wires (0.002-in. and 0.004-in. tungsten) stretched parallel and close to the surface of one or two plates. All of the counters are operated in air at atmospheric pressure. Output pulses of over 200 volts amplitude, rise time of 2×10^{-9} sec, and width of 10^{-8} sec are obtained with a counter deadtime of about 20 μsec. These pulses are capable of driving a scaler without any additional electronic amplification. The double plate counter has a thermal neutron sensitivity of $\frac{1}{10}$ of the sensitivity of a 1-in. o.d.×6-in. enriched BF_3 counter filled to a pressure of 12 cm Hg. Plateaux of over 1000 volts are obtained. A prototype detector, with greater sensitivity and less effective deadtime, will be discussed.

Y7. Millimicrosecond Neutron Spectrometry. I. Multichannel Time Analyzer. J. H. NEILER, G. G. KELLEY, AND P. R. BELL, *Oak Ridge National Laboratory.*—A time interval-pulse amplitude converter has been constructed to permit the use of standard ORNL multichannel pulse analyzers for time interval analysis. The useful range of the instrument is 10^{-8} to 10^{-6} second with a time resolution of less than 10^{-9} second for fast pulses from a mercury relay pulser and $3\text{–}5\times 10^{-9}$ second for annihilation radiation pulses in a pair of scintillation counters. Used with pulsed accelerator neutron sources the converter provides multichannel time-of-flight analysis for neutrons of energies ranging from 2 kev to 15 Mev. Two types of detector are used to cover the full energy range. For energies of 2 kev to ~1 Mev the 478-kev γ rays from the $B^{10}(n,\alpha\gamma)Li^7$ reaction in a slab of enriched B^{10} are detected by NaI(Tl) crystals and RCA 6342 photomultipliers. In the high-energy range proton recoils in an organic phosphor are observed by photomultipliers.

Y8. Millimicrosecond Neutron Spectrometry. II. A Pulsed Ion Source. VINCENT E. PARKER* AND RUTLEDGE F. KING, *Oak Ridge National Laboratory.*—The apparatus consists of a Moak-type rf ion source, a unipotential electrostatic lens, and two pairs of rf deflector electrodes. The design permits the Van de Graaff accelerator to function normally without rf deflector voltage. Tests were made on a bench and on a 625 kv cascade accelerator. Pulse lengths were calculated from the time spread of the gamma rays from the $Li^7(p,\gamma)$ reaction produced by bombarding a lithium target with a 500-kev pulsed proton beam. The gamma rays were detected by a NaI crystal and RCA 6342 photomultiplier tube, and the time spread measured with a multichannel time analyzer. The pulses were 16 millimicroseconds wide at half-maximum and a repetition rate of 10^6 per second. Average pulsed beam current on the target was 1.5 microampere, about one percent of the unpulsed beam. An improved model was designed with careful attention to spherical aberrations in the unipotential lens. This model produces a better focus, larger beam currents, and shorter pulses. Transit time of the beam through the deflector electrodes limits the minimum pulse length attainable. Pulses were produced shorter than 10 millimicroseconds.

* Research participant from Lousiana State University.

Y9. Millimicrosecond Neutron Spectrometry. III. Pulsed Van de Graaff. H. E. BANTA, R. F. KING, AND J. P. JUDISH.—The ion beam pulser described by Parker and King has been installed in the terminal of the ORNL 3 Mv Van de Graaff. The Einzel lens which is a part of the pulser assembly then becomes a part of the terminal lens, and the normal operation of the Van de Graaff machine is not affected. The application of the sine wave deflection voltage in the pulser results in an interrupted ion current from the machine; the ion pulse can be made less than 10^{-8} sec in duration. A 500-kc deflection oscillator is used to give the required 1-mc repetition rate. The resulting over-all resolution of the machine and the time-of-flight electronics is 6.6×10^{-9} sec, as measured by means of the $Li^7(p,p'\gamma)$ reaction.

Y10. Millimicrosecond Neutron Spectrometry. IV. Kilovolt Neutron Cross Sections. E. C. SMITH, J. H. GIBBONS, W. M. GOOD, J. H. NEILER, AND H. E. BANTA.—The millimicrosecond time-of-flight apparatus has been adapted to neutron transmission measurements in the energy range 2–35 kev. Neutron bursts of 10^{-8} sec duration are produced by means of pulsed protons and the $Li^7(pn)Be^7$ reaction. Proton energies range to 35 kev above neutron threshold and target to detector distances, depending on energy, vary from 0.35 to 1.45 meters. In the stated energy range the neutron yield is concentrated into the forward angles. A convenient time calibration is afforded by the 478-kev γ rays from $Li^7(pp')Li^{7*}$ since the detector window is already adjusted to observe this identical gamma ray from the $B^{10}(n,\alpha\gamma)Li^{7*}$ reaction. The 2.2, 12, 15, 34 kev[1] total cross-section resonances in bismuth and the 6.5 kev[2] total cross-section resonance in aluminum have been measured. Observed widths at half-maximum increase from 0.35 kev at 2.2 kev to 1.2 kev at 34 kev. The background which is due mainly to normal background in the NaI crystal together with iodine activation is about 30% at 2 kev to 6% at 30 kev.

[1] J. H. Gibbons and H. W. Newson, Phys. Rev. **91**, 209(A) (1953).
[2] Robser, Newson, and Gibbons, Phys. Rev. **95**, 302(A) (1954).

Y11. Millimicrosecond Neutron Spectrometry. V. $Be^9(dn)$-B^{10} Neutron Spectrum. W. M. GOOD, J. H. NEILER, AND J. H. GIBBONS.—The $Be^9(dn)B^{10}$ reaction has a high yield and the energy levels in B^{10} are precisely known. The $Be^9(dn)B^{10}$ reaction neutron spectrum has therefore been re-examined by means of the millimicrosecond spectrometer, with a deuteron bombarding energy of 1.85 Mev. The energy resolution varies with energy from about 6% at the lower neutron energies to about 10% at the higher neutron energies observed. Therefore, groups of neutrons corresponding to excitation of the first two pairs of states and the second two pairs of states in B^{10} were, respectively, not resolved. The background count is mostly natural room background in the detectors and amounts to 30% of the peak count or less.

FRIDAY AFTERNOON AT 2:45

Grand Ballroom

(J. STEINBERGER presiding)

Mesons

Z1. Nuclear Interactions of 2.4-Bev Protons in Methane.* E. R. MOSBURG, C. O. DECHAND, E. C. FOWLER, AND H. L. KRAYBILL, *Yale University*.—Twenty-five nuclear interactions have been observed in a 27×27 cm diffusion cloud chamber containing methane gas at an average pressure of 5 psig and operating in a magnetic field of 7700 gauss. The interactions were produced by a total of 70 000 beam protons of average energy 2.4 Bev from the Brookhaven Cosmotron. The total observed track length has not yet been determined. The observed numbers of secondaries are as follows:

No. secondaries	2	3	4	5	6	7	8	9
No. events	13	2	2	2	2	2	0	2

The ratio of light (<1.5×minimum) to dense secondaries is about one to two, in those stars containing more than two secondaries. All stars in this group have more than one dense track. The angular distributions of minimum and dense tracks will be given. The production of mesons and the separation of carbon and hydrogen events will be discussed.

* Work supported in part by the U. S. Atomic Energy Commission.

Z2. Meson Production in Pion—Deuteron Collisions at 1.4 Bev.* V. P. KENNEY,† *Brookhaven National Laboratory*.—Pion production multiplicity and charge state distributions for π^-,n interactions have been studied with a deuterium-filled diffusion cloud chamber operated in the 1.37-Bev π^- meson beam at the Cosmotron. A total of 180 events, classified as either π^-,n or π^-,p interactions, were observed. Definite identifications were consistent with equal π^-,n-π^-,p total cross sections,[1] and with a ratio of elastic/inelastic collisions for π^-,n as well as for π^-,p events = $\frac{1}{2}$[2]. Analysis of the observed events on this basis indicated a charge state ratio $\sigma(\pi^-+n\rightarrow n+\pi^-+\pi^0)/\sigma(\pi^-+n\rightarrow p+\pi^-+\pi^-)=1.8\pm0.3$. Some 10% of the π^-,n interactions were examples of double meson production. The charge state ratios observed are in agreement with the statistical theory of Fermi, and do not appear consistent, so far as this experiment can determine, with either a $T=\frac{3}{2}$ pion-nucleon interaction or a $T=1$ pion-pion resonance such as that described by Takeda.[3]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Now at the University of Kentucky.
[1] Cool, Madansky, and Piccioni, Phys. Rev. **93**, 249 (1954).
[2] Eisberg, Fowler, Lea, Shephard, Shutt, Thorndike, and Whittemore, Phys. Rev. **97**, 797 (1955).
[3] G. Takeda, Phys. Rev. **100**, 440 (1955).

Z3. Reaction $p+p\rightarrow\pi^++p+n$.* T. H. FIELDS, R. A. REITER, AND R. B. SUTTON, *Carnegie Institute of Technology*.—The total cross section for the above reaction has been measured to be 1.27±0.24 mb at an incident proton energy of 437 Mev. The experimental technique consisted in separating elastically scattered protons from particles accompanying meson production by range discrimination for laboratory angles from 5° to 35°. Kinematics restricts the laboratory angle of the proton from the reaction $p+p\rightarrow\pi^++p+n$ to values less than 35°. The resulting total cross section was then corrected for π^+ mesons and deuterons arising[1] from the reaction $p+p\rightarrow\pi^++d$, as well as for π^+ mesons arising from the reaction being investigated. A further subtraction of twice the total cross section for $p+p\rightarrow\pi^0+p+p$, to allow for protons arising from π^0 production, yielded the above result. This result is in closer agreement with the phenomenological theory as discussed by Rosenfeld[2] than some previous measurements.[3]

* This work was supported by the U. S. Atomic Energy Commission.
[1] T. H. Fields, U. S. Atomic Energy Commission report NYO 7103, unpublished.
[2] A. H. Rosenfeld, Phys. Rev. **96**, 139 (1954).
[3] These measurements are discussed in reference 2.

Z4. Reaction $p+p\rightarrow\pi^0+p+p$.* R. A. STALLWOOD, T. H. FIELDS, J. G. FOX, AND J. A. KANE, *Carnegie Institute of Technology*.—The above reaction has been studied at several energies in the range 346–437 Mev using the external proton beam of the Carnegie synchrocyclotron. Single photons from the decay of π^0 produced in a liquid hydrogen target were detected with a four-counter telescope. Differential cross sections for photons were obtained for three angles of view using 437-

Mev protons. Comparison with photon angular distributions calculated on the basis of an assumed π^0 c.m. energy spectrum yields a total π^0 cross section of 140 ± 30 microbarns for $Ep=437$ Mev. Results at four lower energies for one angle of view yield an excitation function for the reaction between 346–437 Mev. Similar measurements have also been made for 437-Mev proton bombardment of several nuclei from deuterium to lead.

* This work was supported by the U. S. Atomic Energy Commission.

Z5. π^0 Production in $N-P$ Collisions.* A. H. ROSENFELD, F. T. SOLMITZ, AND R. H. HILDEBRAND, *The University of Chicago.*—The total cross section for π^0 production in $N-P$ collisions was measured for a neutron beam of effective energy 380 Mev by detecting the decay γ's from the π^0's through the electron-positron pairs which they made in a nuclear emulsion. The cross section was determined to be 0.62 ± 0.12 mb for a maximum π^0 center-of-mass energy of 45 Mev. This result is compatible with the requirement of charge independence that

$$2\sigma(N+P\rightarrow\pi^0)=\sigma(P+P\rightarrow\pi^+) -2\sigma(P+P\rightarrow\pi^0)+2\sigma(N+P\rightarrow\pi^+ \text{ or } \pi^-).$$

A number of assumptions about the excitation function and the energy and angular distribution of the π^0's had to be made in order to derive a total cross section from the experimental data, but it can be shown that the result is not very sensitive to the details of the assumptions. The experimental technique will be described, and the relative merits of nuclear emulsions and other detectors of γ rays will be discussed.

* Research supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

Z6. Differential Cross Sections for Pion-Proton Scattering at 220 Mev. M. O. STERN, J. ASHKIN, J. P. BLASER, AND F. FEINER, *Carnegie Institute of Technology.*—Counter measurements have been made of the elastic and charge exchange scattering of 220-Mev π^+ and π^- mesons on hydrogen. The π^+ scattering was done with an externally produced beam. Distributions were measured at eight angles and fitted to a relation $a+b\cos\theta+c\cos^2\theta$ in the center of mass. Values obtained for the constants were $a=5.9\pm0.5$, $b=4.2\pm0.6$, $c=16.3\pm1.3$ for π^+ scattering, $a=0.87\pm0.06$, $b=0.26\pm0.08$, $c+2.03\pm0.17$ for π^- elastic scattering, $a=3.87\pm0.16$, $b=1.30\pm0.18$, $c=4.31\pm0.39$ for the γ-ray distribution from charge exchange scattering. All values are subject to an uncertainty in scale of 4%. Preliminary phase shifts obtained graphically will be presented. No evidence was found for a d-wave contribution.

Z7. Interactions of 1.4-Bev π^- Mesons with Helium Nuclei.* ANATOLE M. SHAPIRO, *Harvard University.*—The Brookhaven magnet diffusion cloud chamber,[1] filled with helium, was exposed to the 1.4-Bev π^--meson beam from the Cosmotron. Approximately 7000 pictures, in stereoscopic pairs, have been scanned to date and 83 interactions have been observed. Of these, 68 have been partially analyzed and classified initially according to the number of emerging charged particles:

No. of emerging tracks	1	2	3	4	5	>5
No. of events	13	19	29	1	6	0

In many events slow recoil deuterons, tritons, and He^3 nuclei can be identified and it can be shown that the incident pion interacts primarily with only one nucleon. Consequently the ratio $\sigma_{\pi^-\text{-}n}/\sigma_{\pi^-\text{-}p}$ can be determined. The sizeable fraction of 1-prong events indicates a considerable cross section for charge exchange, absorption, and "strange" particle production. The latter two processes are believed to be minor. The observed meson production distributions will be compared with those from 1.4-Bev $\pi^- - p$ interactions.[1]

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] Eisberg, Fowler, Lea, Shepherd, Shutt, Thorndike, and Whittemore, Phys. Rev. **97**, 797 (1955).

Z8. Interpretation of the Second Maximum in $\pi^- - P$ Scattering.* BERNARD T. FELD, *M.I.T.*—The peak in the cross section of negative pions on protons at ~1 Bev, which cannot reasonably be accounted for in terms of a single resonance in the pion-nucleon interaction,[1] has been interpreted as indicating a resonant pion-pion interaction.[2,3] An alternative explanation, which could account for part or all of the effect, is that it could result from a number of overlapping $T=\frac{1}{2}$ resonances in the pion-nucleon interaction. A reasonable fit to the data may be obtained assuming resonances for $J=\frac{1}{2}$, $\frac{3}{2}$, and 5/2 (all positive parity), all of which can lead to a final state consisting of the nucleon isobar ($J=T=\frac{3}{2}$) plus a p-wave pion (inelastic scattering) as well as to elastic scattering. A simple, plausible model predicts roughly equal elastic and inelastic (one pion production) scattering in the region of the resonance. Other predictions concerning the energy and charge distributions of the resulting pions and nucleons will be compared with the predictions of the Dyson and Takeda models.

* This work has been supported in part by the joint program of Office of Naval Research and the U. S. Atomic Energy Commission.

[1] C. N. Yang, Rochester Conference, 1955.
[2] F. J. Dyson, Phys. Rev. **99**, 1037 (1955).
[3] G. Takeda, Phys. Rev. **100**, 440 (1955).

Z9. Reactions of 85-Mev π^+ Mesons in Deuterium.* K. C. ROGERS AND L. M. LEDERMAN, *Columbia University.*—The interactions of 85 ± 8 Mev positive pions in deuterium have been studied in the Nevis diffusion cloud chamber. The following reactions have been observed: $\pi^+ + D\rightarrow\pi^+ + D$ (elastic scattering); $\pi^+ + N + P$ (inelastic scattering); $\pi^0 + P + P$ (charge exchange scattering); $\gamma + P + P$ (radiative absorption); $P + P$ (mesic absorption). Charge exchange and radiative absorption processes are identified by two low-energy protons. The directions of the unchanged particles are determined by kinematics. Angular distributions for elastic, inelastic, and charge exchange scattering will be presented. Based on a total of 267 events observed in 27 000 photographs the following relative cross sections have been determined. $\sigma_{E+I}/\sigma_{\text{Tot.}}=66.4\pm5.0\%$; $\sigma_{\text{Ch.X.}}/\sigma_{\text{Tot.}}=20.3\pm2.8\%$; $\sigma_{\text{Abs}}/\sigma_{\text{Tot.}}=11.7\pm2.1\%$; $\sigma_{\text{R.A.}}/\sigma_{\text{Tot.}}=1.6\pm0.9\%$. The purely elastic contribution is observed down to 20° laboratory scattering angle and represents approximately 25% of the total cross section. Absolute cross sections are being determined.

* This research was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

FRIDAY AFTERNOON AT 2:45

Boston Room

(R. SERBER presiding)

Theoretical Physics, VII

ZA1. Three-Dimensionality of Space and the Masses of Nuclei. ENOS E. WITMER, *University of Pennsylvania.*—The mass of any nucleus in any state may be written as Mm, where m is the rest mass of the electron. If m is taken as 0.000548770873 amu, M is given in the ground state to a very high degree of accuracy for $A\leqslant4$ by the simple approximate

formula

$$M=(7/2)^6A-(139/64)(1-\delta_{Z0})3^{(A-1)}+(23/64)[\delta_{N1}+(A+1)\delta_{N2}-6\delta_{A4}]. \quad (1)$$

This formula includes the proton and neutron masses. The prevalence of the number 3 as well as its relatives 6 and 7/2 suggests that the three-dimensionality of space may be involved here. This is an attractive *a priori* idea. Also $(139/64)\cong(7/2)^6(\alpha/2\pi+\frac{1}{4}\alpha^2)$ and $139\cong6\times23$. Other aspects of these regularities will be mentioned.

ZA2. Proposing an Experiment on the Role of the Negative Protons, the Negatrons. GERTRUDE T. SCHWARZMANN.—Introduction of a positron beam into the apparatus wherein proton pairs are being produced should result in the formation of neutrons with negatrons as central bodies and He^4 nuclei, supposed to consist of two pairs, proton plus neutron, revolving in opposite senses about a common center, each negatron co-orbital to the proton revolving in the same sense. The force of attraction between central body and satellite exceeds in the neutrons that in hydrogen atoms by a factor A, 137/2 and 137 its unattainable limits. Interpreting the mass defect of any satellite as the mass equivalent to its total energy and the mass defect of an atom as the sum of the mass defects of its intranuclear satellites A is at least 132 in nuclear neutrons of both kinds. A varying directly with the degree of negativity of the negatron's; inversely with the degree of positivity of the proton's charge all natural nuclei from He^4 onward are supposed to contain Z co-orbital pairs as prerequisite to their very existence. This paper is founded on previously outlined assumptions.*

* Phys. Rev. **92**, 536, 744 (1947); **99**, 662, 677 (1955).

ZA3. Scattering Cross Sections of Cylinders and Spheres at High Frequencies. T. T. WU,* *Harvard University* (introduced by R. W. P. King and J. H. Van Vleck).—The total scattering cross section in the short wavelength limit has been studied in detail for several special geometrical configurations. For the diffraction of a plane electromagnetic wave by a perfectly conducting cylinder (either polarization), the contribution to the total field by the various diffracted rays may be separated by a suitable Green's function. This leads to a representation of the forward field that is particularly appropriate for asymptotic evaluation at high frequencies. A procedure can then be given to find as many terms of the asymptotic expansion as desired. An extension of this process yields similar results for the problems of the quantum-mechanical scattering by an impenetrable sphere, the acoustic scattering by a rigid sphere, and the electromagnetic diffraction by a perfectly conducting sphere. In each case the asymptotic expansion is a power series in $(ka)^{-1}$, where k is the wave number and a is the radius of the cylinder or sphere. In particular, the first six terms for the cross section have been found explicitly in terms of definite integrals independent of ka, the first term being the geometrical-optics result.

* Gerard Swope Fellow of the General Electric Company; also supported in part by Office of Naval Research contract N5ori-76, T.O. 1.

ZA4. Weakened Symmetry Condition on Stochastic Kernels.* JOEL L. LEBOWITZ,† *Syracuse University*.—We have introduced a model for an irreversible process, in which a thermodynamic system of arbitrary structure interacts impulsively with inexhaustible reservoirs.[1] It obeys in its γ space a Liouville equation, augmented by a stochastic integral term. The kernel of this term was postulated to possess a certain symmetry. This symmetry condition has been found to be unnecessarily severe. It can be weakened to a condition somewhat similar to "semidetailed balance".[2] This new condition is both necessary and sufficient to yield these properties: (1) If driven by a single reservoir, the distribution function of the system approaches the canonical distribution asymptotically. (2) With several reservoirs, the Onsager reciprocal relations are satisfied for near-equilibrium conditions.

* Partially supported by Office of Scientific Research, U. S. Air Force.
† General Electric Gerard Swope Fellow.
[1] P. G. Bergmann and J. L. Lebowitz, Phys. Rev. **99**, 578 (1955).
[2] E. C. G. Stückelberg, Helv. Phys. Acta **25**, 577 (1952).

ZA5. Relativistic Molecular Velocity Distribution in a Gas. RICHARD SCHLEGEL, *Michigan State University*.—The effect of relativistic mass increase on the Maxwell-Boltzmann distribution law was considered by Jüttner,[1] using the laboratory coordinate system molecular velocities in the mass-velocity equation. Properly the relative velocity between two interacting molecules should be obtained by applying the three-dimensional Einstein velocity addition equation to the laboratory system molecular velocities. Using that equation and the molecular chaos hypothesis the mean interaction velocity of a molecule is found to be given by $s_i=u_i(1-2kT/mc^2)$, where u_i is a component of the molecular velocity in the laboratory coordinate system, $i=1,2,3$, k is Boltzmann's constant, m the molecular rest mass, and T the temperature, and where terms beyond the first power in $1/c^2$ are neglected. The most probable speed s_m is given by $s_m=u_m(1+u_m^2/c^2)$, where $u_m=(2kT/m)^{\frac{1}{2}}$. The relativistic velocity distribution law (for a nondegenerate gas) is found to contain the correction factors obtained by Jüttner, $(1+15/8B)^{-1}(1-u^2/c^2)^{-\frac{5}{2}}$, where $B=mc^2/kT$, an additional constant factor, $(1-4/B)^{3/2}$, and a velocity dependent factor, $\exp(2u^2/c^2)$. The corrections are found to be nontrivial for an electron gas at 10^8 °K, or for hydrogen gas at 10^{10} °K.

[1] F. Jüttner, Ann. Physik **34**, 856 (1911).

ZA6. Effect of Non-Boltzmann Statistics Upon the Higher Order Kinetic Theory Terms Improving the Navier-Stokes Equation. E. V. LAITONE, *University of California, Berkeley*.—The use of the Boltzmann statistics in the usual Maxwell-Boltzmann integral equation is investigated. The indications are that the Boltzmann statistics, implying molecular independence or "chaos," are applicable only to the equilibrium state. It is shown that the quantum-statistical theory of transport phenomena by Ono[1] indicates that the Uehling-Uhlenbeck[2] equation for degenerate gas analysis may be better suited for kinetic theory development of the higher order terms to improve the Navier-Stokes equations of motion for an ordinary gas, even though Ono[1] has shown that the Uehling-Uhlenbeck collision integral may not be valid for transport phenomena in a degenerate gas. There is shown to be an analogy between the improved collision integral for arbitrary statistics and Jeans's[3] concept of the persistence of velocities for elastic sphere molecules.

[1] S. Ono, Prog. Theoret. Phys. **12**, 113 (1954).
[2] E. A. Uehling and G. E. Uhlenbeck, Phys. Rev. **43**, 552 (1933).
[3] J. H. Jeans, *Dynamical Theory of Gases*, fourth edition (1925), p. 260.

ZA7. Implications of Maxwell's Equations for Unitary Field Theories. PAUL J. KELLOGG, *Naval Research Laboratory*.—In considering "unitary field theories" which involve the electromagnetic field, we are led to consider solutions of Maxwell's equations which satisfy (1) $\rho\mathbf{E}+\mathbf{j}\times\mathbf{B}=0$. This expression is the divergence of the Maxwell stress tensor, hence[1] is the condition that the electromagnetic self-energy of the charge and current distribution ρ, j, transforms like that of a particle under Lorentz transformations. One-dimensional solutions can be easily found. Qualitative arguments based on these solutions make it possible to understand why quantization would imply a unique value of the fine structure constant α. The value of α depends on the details of the field equations determining ρ and j.

[1] R. J. Finkelstein, Phys. Rev. **75**, 1079 (1949).

ZA8. Generalization of the Third Law of Thermodynamics. JEROME ROTHSTEIN, *Signal Corps Engineering Laboratories.*—*Theorem:* it is impossible to prepare any physical system in a pure state in a finite number of operations. *Definition:* pure state means pure quantum state, more generally, state of maximal information admitted by underlying microscopic theory. *Statistical postulate:* macroscopic object in pure state taken to have zero entropy. *Proof:* if theorem false, prepare system in pure state. It would then be at absolute zero (Planck) contradicting third law. *Note:* conversely truth of theorem implies third law. *Intuitive version:* mechanics is the thermodynamics of absolute zero. *Salvation of pure states:* though operationally undefined, pure states are extreme points in the set of mixtures, the entire set being the closed convex hull of the extreme points leading to convenient representation of general points as linear combinations of extreme points whence usefulness of pure states is unimpaired. *Significant implications:* (a) impossible to measure even one observable with perfect accuracy (b) predictions and retrodictions become increasingly inaccurate with displacement in time from time of observation; complete spoilage of initial information occurs in time analogous to time for system to come to equilibrium (c) an informational interpretation of statistical entropy and Gibbsian ensembles is indicated.

SUPPLEMENTARY PROGRAMME

SP1. Remarks on a Note by Mitrinovitch.* STANLEY WINKLER, *Army Electronic Proving Ground.*—It is shown that the Riccati-type equation given by Mitrinovitch[1]

$$(dy/dx)+y^2=a(\theta'/\theta)^2+\tfrac{3}{4}(\theta''/\theta')^2-\tfrac{1}{2}(\theta'''/\theta')$$

(where the primes denote differentiation with respect to x; θ is a nonconstant function of x; and a is a nonzero constant) reduces to the equation

$$(du/dt)+u^2=at^2,$$

whose solution was known to Euler prior to 1769 and probably to Daniel Bernoulli (*circa* 1725). Mitrinovitch's equation is actually a simple particular case of an equation discussed by Rawson[2] which is equivalent to the so-called Special Riccati Equation. It is therefore possible to express all the results of Mitrinovitch in a somewhat simpler and perhaps more familiar form.

* To be given at the end of Session C if the Chairman rules that time permits.

[1] Mitrinovitch, Compt. rend. **228**, 1188–1190 (1949).

[2] Rawson, Mess. Math. **12**, 34–36 (1883).

SP2. Subtraction Prescription for Closed-Loop Divergences.* T. A. WELTON, *Oak Ridge National Laboratory.*—Although the photon self-energy and infinite charge renormalization of quantum electrodynamics apparently now offer only questions of principle, the existence of analogous difficulties in pseudo-scalar meson theory is in practice very serious because of the absence of gauge invariance to guide the choice of subtraction recipe. A formulation of relativistic quantum theory in a space of four equivalent dimensions offers a promising subtraction procedure. The fermions are given a rest mass constant n, and the desired vacuum polarization calculated. The result is necessarily convergent, since the quadratic form p^2 is now positive definite and equal to n^2. This result is interpreted as the discontinuity possessed by the desired function across the real axis of n. Calculation of the desired physical result can then be accomplished by evaluating the complex function at $n=im$ (m=actual fermion mass). No photon mass appears, but an obviously improper use of the Cauchy theorem formally yields all the other diverging and observable results of the conventional theory. A rigorous attack yields vanishing results for all the usual divergences. Finite, observable results are largely left unaltered, an interesting exception being the decay rate of the neutral pion, where the usual triangle diagram now vanishes.

* To be given at the end of Session L if the Chairman rules that time permits.

SP3. When Does First-Order Perturbation Theory Give Exact Solutions?*† M. A. MELVIN, *Florida State University.*—Given a degenerate energy level G of a Hamiltonian $\boldsymbol{H}_0$ of a physical system. It may happen that when the system is perturbed with an added Hamiltonian $\boldsymbol{V}$, the eigenfunctions of the perturbed—and possibly split-level are all obtained from those of the parent level by linear combination; in this case one may say that the parent level is *endogamously*[1] *perturbed under* $\boldsymbol{V}$. It is easy to prove that the shifts and splittings of G will be exactly given by first-order perturbation theory if G is endogamous under $\boldsymbol{V}$. It is evident that the occurrence of endogamous levels in a given microphysical system under suitable perturbations may lead to a useful and unambiguous test of various theories of the structure and interactions of the system. A simple group-theoretic criterion is given for picking out which levels of any system of a given symmetry are endogamous under perturbations of various subsymmetries. Tables of such levels for all the common point symmetry groups are presented.

* To be given at the end of Session W if the Chairman rules that time permits.

† This work was assisted by the U. S. Atomic Energy Commission.

[1] From the anthropological significance meaning "marrying only within the tribe."

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